MONOGRAPHS ON BIOCHEMISTRY

EDITED BY

R. H. A. PLIMMER, D.Sc.

AND

SIR F. G. HOPKINS, M.A., M.B., D.Sc., F.R.S.

GENERAL PREFACE.

THE subject of Physiological Chemistry, or Biochemistry, is enlarging its borders to such an extent at the present time, that no single textbook upon the subject, without being cumbrous, can adequately deal with it as a whole, so as to give both a general and a detailed account of its present position. It is, moreover, difficult in the case of the larger textbooks to keep abreast of so rapidly growing a science by means of new editions, and such volumes are therefore issued when much of their contents has become obsolete.

For this reason an attempt is being made to place this branch of science in a more accessible position by issuing a series of monographs upon the various chapters of the subject, each independent of and yet dependent upon the others, so that from time to time, as new material and the demand therefor necessitate, a new edition of each monograph can be issued without re-issuing the whole series. In this way, both the expenses of publication and the expense to the purchaser will be diminished, and by a moderate outlay it will be possible to obtain a full account of any particular subject as nearly current as possible.

The editors of these monographs have kept two objects in view: firstly, that each author should be himself working at the subject with which he deals; and, secondly, that a *Bibliography*, as complete as possible, should be included, in order to avoid cross references, which are apt to be wrongly cited, and in order that each monograph may yield full and independent information of the work which has been done upon the subject.

R. H. A. P.
F. G. H.

MONOGRAPHS ON BIOCHEMISTRY

EDITED BY

R. H. A. PLIMMER, D.Sc.

AND

SIR F. G. HOPKINS, M.A., M.B., D.Sc., F.R.S.

8vo.

THE NATURE OF ENZYME ACTION. By Sir W. M. BAYLISS, M.A., D.Sc., F.R.S. Fifth Edition. 9s. net.

ALCOHOLIC FERMENTATION. By ARTHUR HARDEN, Ph.D., D.Sc., F.R.S. Third Edition. 6s. 6d. net.

THE PHYSIOLOGY OF PROTEIN METABOLISM. By E. P. CATHCART, M.D., D.Sc., F.R.S. Second Edition. 12s. 6d. net.

THE VEGETABLE PROTEINS. By THOMAS B. OSBORNE, Ph.D., Sc.D. Second Edition. 9s. net.

THE CARBOHYDRATES AND THE GLUCOSIDES. By E. FRANKLAND ARMSTRONG, D.Sc., Ph.D., F.R.S. Fourth Edition. 16s. net.

OXIDATIONS AND REDUCTIONS IN THE ANIMAL BODY. By H. D. DAKIN, D.Sc., F.I.C., F.R.S. Second Edition. 6s. net.

LECITHIN AND ALLIED SUBSTANCES. THE LIPINS. By HUGH MACLEAN, M.D., D.Sc. and IDA SMEDLEY MACLEAN, D.Sc., F.I.C. Second Edition.

NUCLEIC ACIDS. Their Chemical Properties and Physiological Conduct. By WALTER JONES, Ph.D. Second Edition. 9s. net.

THE CHEMISTRY OF UREA. The Theory of its Constitution, and of the Origin and Mode of its Formation in Living Organisms. By EMIL A. WERNER, M.A., Sc.D., F.I.C. 14s. net.

THE FATS. By J. B. LEATHES, M.A., M.B., F.R.S., and H. S. RAPER, C.B.E., M.B., Ch.B., D.Sc. Second Edition. 12s. 6d. net.

HEXOSAMINES AND MUCOPROTEINS. By P. A. LEVENE. 10s. 6d. net.

LONGMANS, GREEN AND CO. LTD.

London, New York, Toronto, Bombay, Calcutta and Madras.

LECITHIN AND ALLIED SUBSTANCES

THE LIPINS

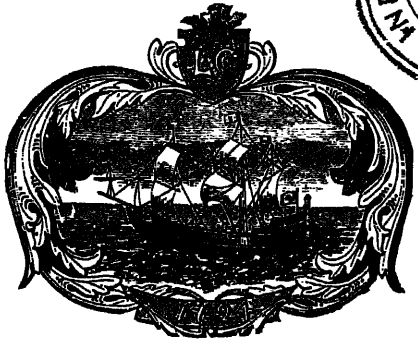
BY

HUGH MACLEAN, M.D., D.Sc.

PROFESSOR OF MEDICINE IN THE UNIVERSITY OF LONDON; ST. THOMAS'S HOSPITAL

AND

IDA SMEDLEY MACLEAN, D.Sc.



NEW EDITION

LONGMANS, GREEN AND CO. LTD.

39 PATERNOSTER ROW, LONDON, E.C. 4

NEW YORK, TORONTO

BOMBAY, CALCUTTA AND MADRAS

1927

Made in Great Britain

PREFACE.

SINCE the appearance of the first edition of this monograph, no fundamental advances have been made in our knowledge of the chemistry of the lipins; the detailed structure of lecithin and kephalin has, however, been further worked out, notably by Levene and his colleagues. In the previous edition of this volume cuorin was tentatively included among the lipins as a definite chemical entity: the work of the past few years has removed it from the already short list of lipins of unchallengeable chemical individuality, and it has now definitely been proved to be a mixture.

We contemplated omitting any historical account of the Protagon controversy from the present edition of this volume, but the story of Protagon still seems to contain lessons of considerable interest to those who are starting work in the difficult field of lipin chemistry, and this section has therefore been included in a somewhat abbreviated form.

The vexed question of nomenclature presents considerable difficulty. At the International Conference of Chemistry held in 1923, the Commission for the Reform of the Nomenclature of Biological Chemistry recommended the use of the term "lipides" to include the groups of phosphatides and cerebrosides. The introduction of another new word appears to us unnecessarily confusing, and we have therefore retained the term "lipin" throughout and have followed Leathes in using the terms phospho- and galacto-lipins for the two groups termed by Thudichum the phosphatides and cerebrosides. This practice also presents the advantage of bringing the nomenclature used in this volume into line with that used by Leathes and Raper in their volume on Fats in this series.

In the chapter on the biological significance of the lipins, some of the lines of work which appear to us to be most suggestive have been indicated. We are still without definite knowledge as to the part played by the lipins in the animal organism, but there are some indications that we are approaching nearer to a better understanding of the rôle of these essential constituents of all living cells.

H. M.
I. S. M.

November, 1926.

CONTENTS.

CHAPTER I.

INTRODUCTION AND NOMENCLATURE.

When animal or vegetable tissues are extracted with ether or with certain other organic solvents, the soluble material consists of ordinary fat together with a variable amount of other substances. Many of these substances are of fatty nature and yield fatty acids on hydrolysis, but differ from neutral fat in that they contain nitrogen or nitrogen and phosphorus in the molecule. Others bear no resemblance whatever to fat except the accidental one of being soluble in the ordinary fat solvents. The ether or alcohol extract of a tissue or organ is therefore composed of a heterogeneous mass of substances which may be roughly classified as follows :—

A. Neutral fat and fatty acids.

B. Substances of varying chemical nature having no relation to fat, such as cholesterol and certain pigments.

The "fat-like" bodies or "Lecithin and allied substances."

C. Substances containing fatty acids, nitrogen, and phosphorus. The Phospholipins or Phosphatides. Of the phosphatides the best known is lecithin.

D. Substances containing fatty acids, nitrogen and a carbohydrate group, but no phosphorus. The Galactolipins or Cerebrosides.

Many of these "fat-like" bodies are difficult to separate and to obtain in a pure state, and much confusion prevails regarding their number and chemical properties. Various terms have been introduced from time to time to designate these substances, and often they are in a general way referred to as "lipoids." The term lipoid was used by Kletzinski to signify all the unsaponifiable substances that could be extracted from tissues by alcohol and ether. It was reintroduced by Overton [1901], and used by him to denote all those cellular components which dissolve in organic solvents, such as chloroform, alcohol and ether. The word "lipoid" is now employed in such a

vague and unsatisfactory sense that it is often by no means clear what it is intended to indicate. Some writers use the term with particular reference to the "fat-like" bodies—phospholipins and galactolipins: others employ it in Overton's sense. Some include neutral fat under the term while others talk of "fats and lipoids." If the word lipoid were used exclusively to denote the "fat-like" bodies its derivation (λίπος = fat) might substantiate this usage. If, as so often happens, it embraces such diverse substances as cholesterol and pigments, the name ceases to have any chemical significance, since the only relationship between these bodies and fat is limited to the physical one of common solubilities in certain solvents.

Any suggestion to restrict the term exclusively to its legitimate groups—the galactolipins and phospholipins—would simply result in chaos, for in much of the older literature the name would still indicate a more or less extended list of substances according to the particular ideas of the individual author. On the whole, it would appear best to use the word lipoid to designate the ether-soluble substances extracted from the tissues. It is convenient to have a term with this meaning, and in the literature the word is most frequently used in this sense.

Under the heading, "Lecithin and allied substances," as used in this monograph, are included the two classes of "fat-like" bodies mentioned:—

A. The Phospholipins or Phosphatides.
B. The Galactolipins or Cerebrosides.

These two groups of substances have the property in common of furnishing fatty acids or their derivatives on hydrolysis, and some generic name to include both groups is useful. Though in many cases the composition of the bodies comprising them is still obscure, we have of late years obtained some insight into their general structure, and they are now sufficiently well characterised to justify their inclusion under some designation which renders allusion to them more convenient. For this purpose the term "lipins" was suggested in the first edition of this monograph. The word *lipin* was used by Leathes [1910] to denote an indefinite class of substances investigated by Thudichum and called by him amidolipotids. According to Thudichum these bodies (bregenin and krinosin) are compounds of fatty acids and contain nitrogen, but no phosphorus or carbohydrate group. Their existence in the tissues (brain) as preformed substances is exceedingly doubtful, and it seems probable that they are decomposition

products. For the present their acceptance as pre-existing substances is unwarranted, and the term "lipin" seems more suitable as a class name to include the cerebrosides and phosphatides: if future research should substantiate the existence of the amidolipotids they would also be included.

Since the term was employed by Leathes, it has been extensively used, especially by American authors, but the sense in which they employ it is entirely different from that suggested by Leathes. Many of these authors use the term virtually to replace the old word "lipoid." Thus Rosenbloom [1911] employs the term lipin to designate practically all the known bodies which are extracted from cells by alcohol and ether, along with certain artificial products not found in cells. Under this heading they include such diverse bodies as lecithin, lipochromes, cholalic acid, lead oleate and cholesterol. There can be no justification for introducing the term *lipin* to be used in exactly the same way as the term *lipoid.* It is perhaps convenient to keep the latter term to denote the ether-soluble substances which are extracted from the tissues, and which consist chiefly of lipin, cholesterol and fat. Doubtless it is more exact to denote the mixture of substances obtained in the alcohol or ether extract of an organ by the terms "alcohol extract" or "ether extract," but the retention of the term "lipoid" for the ether-soluble constituents of a tissue may be justified on the score of convenience.

In these pages the term "lipin" will be employed as a class name to include the cerebrosides or galactolipins and the phosphatides or phospholipins. The exclusive use of the word in this sense would simplify matters materially and save much repetition. Thus in the application suggested the term might be defined as follows:—

Lipins are substances of a fat-like nature yielding on hydrolysis fatty acids or derivatives of fatty acids, and containing in their molecule either nitrogen or nitrogen and phosphorus.

The use of the term "lipides" in exactly the same sense as the term "lipins" as defined above was recommended at the International Conference of Chemistry in 1923 by the Commission for the reform of the nomenclature of biological chemistry. The introduction of the new term "lipide" does not appear to us to possess any advantages over the term "lipin" and we have therefore not adopted it.

CLASSIFICATION OF LIPINS.

Many classifications of these bodies have been attempted, but all are unsatisfactory, owing chiefly to the difficulties experienced in isolating the different substances in a chemically pure form. This difficulty is complicated by the property which many of these bodies possess, of being intersoluble. The result is that mixtures of two or more lipins have from time to time been considered as separate entities and duly given a name. On analysis such mixtures tended to give complicated results, so that an extended and more ample classification was gradually evolved. It will be shown later that the number of lipins, as to whose existence as chemical individuals we have definite evidence, is comparatively small, and it is hoped that the present plethora of unnecessary terms will be gradually eliminated from the literature.

The two groups of bodies (phosphatides and cerebrosides) included under the term lipin have received various names. The term phosphatide, as pointed out by Leathes, has certain disadvantages which are perhaps more theoretical than real, but it does possess the advantage that its application is well defined and indicates a definite group of substances. After all, in dealing with such ill-characterised bodies as the lipins, of which it may be said that the exact chemical structure of even one of them is not known with certainty, the nomenclature, seeing it cannot be based on chemical principles, is of minor importance, provided that the sense in which the term is used is strictly defined. The word "phosphatide" fulfils this condition, and its long and international usage justifies its retention. The suggestion of Leathes that the terms "phospholipines" and "galactolipines" should be used to replace "phosphatides" and "cerebrosides" respectively has, however, much to be said in its favour, and has been adopted in the present edition of this monograph. In order, however, to bring the termination into line with that of lecithin and kephalin, the authors propose to omit the final "e" and use the terms phospho- and galacto-lipins.

Koch [1903] suggested the name "lecithans" for this class of bodies, but its use has not become general. The cerebrosides have also received different names. No final classification of the lipins can be adopted until research has succeeded in ascertaining the chemical constitution of these substances.

The Phospholipins (Phosphatides).

The phospholipins comprise a group of bodies, most of which are of plastic consistency and have distinct fat-like properties. They occur abundantly in eggs, brain, heart, muscle, liver and other organs, and appear to be present in every animal and vegetable cell so far investigated.

Generally speaking, they are soluble in the majority of ordinary solvents for fat, with the exception of acetone, in which they are practically insoluble. Advantage is taken of this property to separate them from other fatty substances. They all contain phosphorus, nitrogen and fatty acids, and on hydrolysis yield phosphoric acid (generally in the form of glycerophosphoric acid) together with various fatty acids and basic bodies, such as choline and amino-ethyl alcohol. They form compounds with cadmium chloride, platinum chloride and many metallic salts. They also form combinations with certain organic substances such as protein. Many of them swell up in water to form colloidal solutions, from which they can be separated by the addition of sodium chloride and other salts.

The most general classification of the phospholipins is that introduced by Thudichum, in which they are divided into groups depending on the relation of the nitrogen to phosphorus present. Thus, in lecithin and kephalin, one atom of nitrogen and one atom of phosphorus occur, so that in these bodies the N : P ratio is 1 : 1; in sphingomyelin the N : P ratio is 2 : 1.

This empirical classification has little to recommend it, except expediency, but until our knowledge of these substances is much extended it is difficult to replace it by a better one. All the later classifications on this principle are based on this original sub-division of Thudichum, which can be extended indefinitely to embrace substances with any N : P ratio whatever.

The phospholipins described would be classified in the following sub-groups :—

I. Monaminomonophospholipins (N : P = 1 : 1), Lecithin and kephalin.

II. Diaminomonophospholipins (N : P = 2 : 1), Sphingomyelin.

The Galactolipins (Cerebrosides).

The galactolipins represent a group of nitrogenous bodies which contain no phosphorus. The members of this group occur chiefly in

the brain, and are characterised by the fact that on hydrolysis they furnish the reducing sugar galactose. The galactolipins are white powders which may be crystalline or of a waxy appearance, thus differing physically from the majority of the phospholipins, which are plastic non-crystalline bodies. They tend to occur in nature especially in company with one of the phospholipins—sphingomyelin—which, in certain of its solubilities and physical properties, resembles the galactolipins and is difficult to separate from them. As a result, the literature of the galactolipins is perhaps more confusing than any other part of the subject of lipins, since a number of different names have been given to bodies which are more or less impure varieties of the same substances, or else mixtures of lipins. Two galactolipins—phrenosin and kerasin—have been definitely identified; recently a third galactolipin—nervon—has been described and appears to have good claims to chemical individuality.

Classification of Lipins.

Since the phospholipins and galactolipins described above are in the writers' opinion the only ones which have been definitely isolated, it is obvious that an elaborate classification is superfluous. The following simple scheme includes them all, and if the future should add to their number, this classification can be easily extended :—

LIPINS.

I. PHOSPHOLIPINS.	II. GALACTOLIPINS.
(A) *Monaminomonophospholipins* (N : P = 1 : 1) (*a*) Lecithin. (*b*) Kephalin.	(*a*) Phrenosin.
(B) *Diaminomonophospholipins* (N : P = 2 : 1) Sphingomyelin.	(*b*) Kerasin. (*c*) Nervon.

Of the phospholipins, the best known are lecithin and the nearly related substance kephalin. A consideration of the structure of lecithin, which may be taken as a type of the phospholipins, at once indicates its relationship to ordinary fat, for we may regard lecithin as a fat in which one of the three fatty acids is substituted by phosphoric acid combined with the base choline.

In a neutral fat each of the three (OH) groups of glycerol is replaced by the fatty acid radical (OOC . R) :—

Glycerol.	*Neutral Fat.*
CH_2 . OH	CH_2 . OOC . R
CH . OH	CH . OOC . R
CH_2 . OH	CH_2 . OOC . R

and if we consider one of these fatty acid radicals replaced by phosphoric acid, and choline introduced, the resulting product represents the structure of lecithin :—

Lecithin.

$CH_2 . OOC . R$
|
$CH . OOC . R$
|
CH_2—Phosphoric acid radical—choline

Kephalin probably possesses a similar structure ; the radicals present in both lecithin and kephalin are of the same nature, with the exception that the choline of lecithin is represented by another base (amino-ethyl alcohol). Besides these two substances many other phospholipins are described. There is, however, only one of these of whose existence as a chemical entity we have any reasonable evidence at present. This is sphingomyelin.

The two phospholipins—lecithin and kephalin—both contain fatty acids of the unsaturated series, which are exceedingly liable to oxidation changes. On this account these bodies are very labile, and their properties and solubilities soon alter on exposure to light and air, so that their extraction and isolation in an unchanged state is attended with great difficulties. Different varieties of these phospholipins may exist, depending on the presence of different fatty acids.

Unlike these bodies, sphingomyelin is a stable substance containing saturated fatty acids, and differs markedly from the other phospholipins mentioned, particularly in its physical properties. It occurs as a glistening white non-hygroscopic powder which does not alter on exposure to air. In many organs only traces of this substance are met with, while in others it has not yet been found. Kidneys and brain contain relatively large amounts. Its exact structure is still under discussion.

Besides the above, various phospholipins of doubtful occurrence which have received special names, together with some special bodies which have received no definite names, have been described. These are discussed at a later stage when dealing fully with the individual phospholipins (Chapter V.).

Other Classifications.

The change in terminology suggested by Leathes is undoubtedly the best of the many attempts to place this difficult subject on a better basis, and the authors propose to use throughout this book the terms

phospholipins and galactolipins in place of the original terms phosphatides and cerebrosides. Leathes' classification has much to recommend it, and possesses the merit of simplicity. All the members of the phosphatides are included under one heading without any attempt at division into groups. On the other hand, though the old subgrouping of the phosphatides in terms of the N : P ratio is purely empirical, it is in practice not devoid of utility.

Leathes' Classification (1910).

I. Phospholipines (Phosphatides of Thudichum).

Compounds of fatty acids containing nitrogen and phosphorus :—

(*a*) Lecithin.
(*b*) Kephalin.
(*c*) Cuorin.
(*d*) Sphingomyelin.
(*e*) Other related but less completely defined substances.

II. Galactolipines (Cerebrosides of Thudichum).

Compounds of fatty acids containing nitrogen and galactose, but no phosphorus :—

Cerebrone, etc. (phrenosin and kerasin).

For a third group the term lipin is employed to denote components of fatty acids containing nitrogen, but no phosphorus or carbohydrate group.

Other older classifications in which provision is made for a great number of substances, whose existence is doubtful or already disproved, are the following :—

Thudichum's Classification (1884).

I. Group of Phosphatides :—

Sub-group of Mononitrogenised Monophosphatides (N : P = 1 : 1).

Lecithins.
Kephalins.
Paramyelins.
Myelins.

Sub-group of Dinitrogenised Monophosphatides (N : P = 2 : 1).

Amidomyelins.
Amidokephalins.
Sphingomyelins.

Sub-group of Dinitrogenised Diphosphatide (N : P = 2 : 2).
Assurin.

Sub-group of Nitrogenised Phosphatide Sulphatide.
Cerebrosulphatide.

Sub-group of Non-nitrogenised Monophosphatides.
Lipophosphoric acid.
Butophosphoric acid.
Kephalophosphoric acid.

II. Group of Nitrogenised Non-Phosphorised Principles :—

Sub-group of Cerebrosides.
Phrenosin.
Kerasin.

Sub-group of Cerebrinacides.
Cerebrinic acid.
Sphaerocerebrin.

Sub-group of Cerebrosulphatides.
Body containing sulphur.

Many other substances such as hypoxanthin and amino acids are also included under Group II.

Bang's Classification (1911), (based on Thudichum's).

I. Phosphatides :—

A. Unsaturated Phosphatides.

(1) *Monaminomonophosphatides* (N : P = 1 : 1).
(*a*) Lecithin.
(*b*) Kephalin.
(*c*) Paramyelin.
(*d*) Vesalthin.

(2) *Monaminodiphosphatides* (N : P = 1 : 2).
(*a*) Cuorin.
(*b*) Liver phosphatide.
(*c*) Egg yolk phosphatide.

(3) *Triaminodiphosphatides* (N : P = 3 : 2).
(*a*) Sahidin.
(*b*) Kidney phosphatide.

B. **Saturated Phosphatides.**

(1) *Diaminomonophosphatides* (N : P = 2 : 1).
- (*a*) Sphingomyelin.
- (*b*) Aminomyelin.
- (*c*) Apomyelin.
- (*d*) Muscle phosphatide.
- (*e*) Egg yolk phosphatide.
- (*f*) Horse pancreas phosphatide.

(2) *Triaminomonophosphatides* (N : P = 3 : 1).
- (*a*) Neottin.
- (*b*) Carnaubon.

(3) *Protagon.*

C. **Phosphatides Insufficiently Characterised.**

II. CEREBROSIDES :—
- (1) Phrenosin.
- (2) Kerasin.
- (3) Cerebron.
- (4) Cerebrin and Homocerebrin.
- (5) Pyosin and Pyogenin.

Other classifications have been suggested by Rosenbloom and Gies [1911] and by Cramer [1911]. The first of these is based on Leathes' terminology. Cramer suggests the following division of the lipins :—

Cramer's Classification (1911).

(1) PHOSPHATIDES.

Nitrogen-containing fatty acid esters of glycero-phosphoric acid. Some phosphatides may have the glycerin substituted by an unknown alcohol.

"Lecithin," "Kephalin," "Sphingomyelin," etc.

(2) GALACTOPHOSPHATIDES.

Nitrogen-containing esters of phosphoric and fatty acids with galactose and alcohol groups.

"Carnaubon."

(3) CEREBROSIDES.

Nitrogen-containing esters of fatty acids and galactose in which no phosphorus is present.

"Cerebron," "Cerebrin," "Homocerebrin," etc.

(4) PHOSPHOCEREBROSIDES.
Cerebrosides with phosphorus-containing groups.
"Protagon."

These various classifications suffice to show the difficulties connected with the subject of the lipins, and they are given in the hope that the reference to them may be helpful in connexion with substances fully discussed in later pages, where it will be shown that many of the bodies mentioned have no justifiable claims to be included as separate entities in the class of lipins.

CHAPTER II.

THE CHEMISTRY OF THE PHOSPHOLIPINS (PHOSPHATIDES)—LECITHIN, KEPHALIN, AND SPHINGOMYELIN.

ONLY those phospholipins which are sufficiently well characterised to be regarded as chemical entities are described in this chapter. They are lecithin, kephalin and sphingomyelin. Of the great number of other substances which different authors have isolated and regarded as phosphatides, many have received definite names such as vesalthin, cuorin, neottin, carnaubon and jecorin, while others are referred to in a general way as diaminophosphatides, triaminophosphatides, etc. Many of these bodies are undoubtedly mixtures of lipins; some are lipins mixed with certain nitrogenous impurities or with products formed by the decomposition of the lipins themselves. A few, including such substances as the myelin of Thudichum, may possibly be true phospholipins, which up to the present have not been sufficiently investigated, but so far there is no evidence available which should lead us to regard them as chemical individuals. A description and discussion of all these alleged phospholipins is deferred to a later period (Chapter VI.) on the ground that their inclusion at this stage would necessarily tend to complicate the subject. Some knowledge of the properties of the better-defined phospholipins, their occurrence, extraction and isolation from the tissues (Chapter III.) is necessary in order to appreciate the reasons why many of these ill-defined substances have no claim to be regarded as definite phospholipins. Indeed, the existence of any product whatever of the nature of phospholipins has been denied by Barbieri (1910, 1912), who, in spite of repeated attempts, completely failed to obtain any trace of lecithin from 3000 eggs!

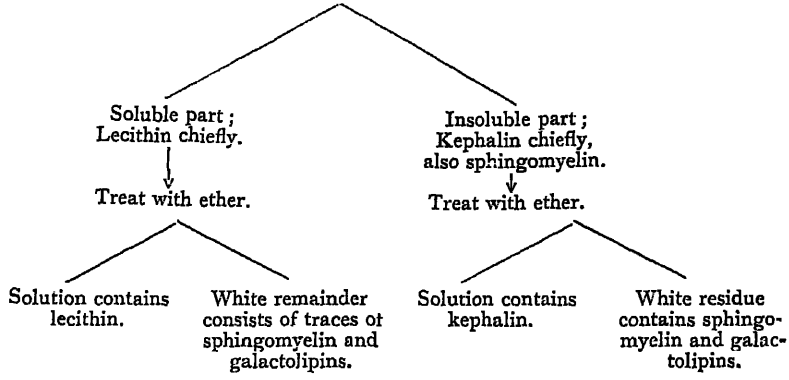
When tissues are extracted with ether or with certain other organic solvents, and acetone is added to the extracts thus obtained, the phospholipins are precipitated. Part of this precipitate is soluble in cold alcohol; the alcohol-soluble fraction is treated with ether, which leaves certain impurities undissolved, and from the ethereal

solution a substance is separated which has a N : P ratio of 1 : 1, and which contains lecithin. The part insoluble in cold alcohol consists chiefly of kephalin contaminated with certain of its own decomposition products. Sphingomyelin (p. 57) may occur in both the alcohol-soluble and alcohol-insoluble portions.

This general relationship is shown in the following scheme :—

SCHEME FOR SEPARATION OF CRUDE PHOSPHOLIPINS.

1. Dried tissue extracted with suitable solvent and extract filtered.
2. Excess of acetone added to filtrate. Lecithin, kephalin, sphingomyelin, and galactolipins are precipitated.
3. *Precipitate extracted with cold alcohol.*



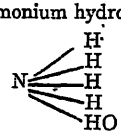
LECITHIN.

The first indication of the occurrence of complex fatty compounds was obtained by Fourcroy [1793]. Later Vauquelin [1812] succeeded in isolating phosphorus-containing fats from the brain. Similar substances also obtained from brain were described by Couerbe [1834]. Though these substances were undoubtedly impure, some of them were probably of the nature of "protagon" (p. 124), while others corresponded more or less to lecithin. To one of these bodies isolated by Vauquelin, the name "oleophosphoric acid" was given by Frémy [1841; 1841, 1; 1841, 2]. Frémy and Valencienne [1857] discovered a similar body in the roe of fish. Later, Gobley [1846, 1847] isolated a compound of the same nature from egg yolk; this substance [1850] he called lecithin (from λέκνθος, egg yolk). Gobley [1850] first demonstrated the presence of glycerophosphoric acid in lecithin. He also recognised that fatty acids and nitrogen were present, but failed to ascertain the nature of the nitrogenous constituent.

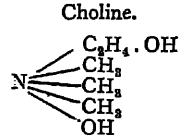
Liebreich [1865] stated that the nitrogen was present as neurine, but this was disproved by Diaconow [1867] and Strecker [1868], both of whom, finding that the platinum chloride compound contained oxygen, came to the conclusion that the base was a body whose platinum chloride compound had the composition $C_5H_{14}NO \cdot Cl \cdot PtCl_2$. Strecker identified it as a body which he had previously [1862] discovered in bile, and which he named choline.

Choline possesses the empirical formula $C_5H_{15} \cdot NO_2$, and may be regarded as a substituted ammonium hydroxide in which one hydrogen atom is replaced by the oxyethyl ($C_2H_4 \cdot OH$) group, and the other three by methyl (CH_3) groups. A description of this compound is given in Barger's monograph [1914].

Ammonium hydroxide.

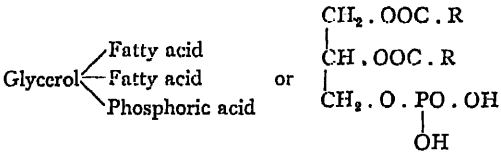


Choline.

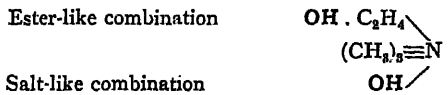


Structure of Lecithin.

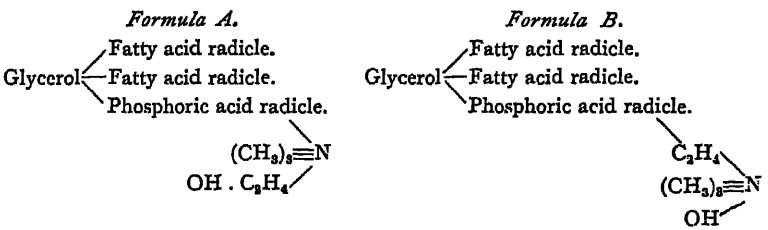
These observations furnished a basis for the chemical constitution of lecithin. Diaconow [1868; 1868, 2; 1868, 3] and Strecker [1868] showed that the fatty acids were combined with the glycerol of the glycerophosphoric acid in the form of an ester:—



These investigators differed, however, as to the manner in which the choline radicle was attached to the phosphoric acid. Combination could obviously take place by substitution of either of the OH groups shown in the choline formula :—

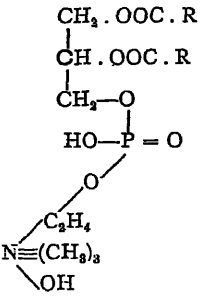


If choline reacted as a substituted ammonium base, its combination with phosphoric acid would be through the lower OH group to form a salt; on the other hand, choline might act as an alcohol, in which case the combination would be between alcohol and acid constituting an ester. The salt-like combination is represented by formula A, in which the OH group attached to the nitrogen of the choline is substituted by the phosphoric acid radicle. Formula B represents the ester-like combination in which the OH group attached to the carbon (i.e. the OH group of an alcohol radicle) is substituted by the phosphoric acid radicle :—



Diaconow [1868, 3] considered lecithin as a compound in which the choline was present in salt-like combination, while Strecker [1868] claimed that the combination was really in the form of an ester. Strecker's observation was confirmed by Hundeshagen [1883] and Gilson [1888], and though questioned by Malengreau and Prigent [1912], is generally accepted. Lecithin is therefore regarded as a body consisting of two fatty acid radicles, one glycerophosphoric acid radicle and one choline radicle, these substances being bound together as represented in the following formula :—

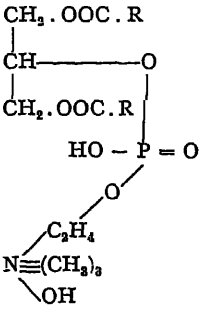
Lecithin Asymmetrical Formula.



This formula contains an asymmetrical carbon atom (the C of the second glycerol group shown in heavy type) attached to four different radicles or atoms, and the substance should therefore be optically active.

It is obvious from theoretical considerations that it is possible to construct another formula in which the phosphoric acid is linked with the middle carbon atom of the glycerol, thus :—

Lecithin Symmetrical Formula.



Such a body would be isomeric with that represented by the asymmetrical formula given above ; it would be optically inactive provided that both fatty acids were identical. Since lecithin is optically active (Ulpiani, 1901 ; 1901, 1), and, according to Willstätter and Lüdecke [1904] furnishes optically active glycerophosphoric acid on hydrolysis, the asymmetrical formula is generally regarded as the correct one, but the possibility of the existence of both isomers must be considered. (Tutin and Hann, 1906 ; Bailly, 1915 ; see also Glycerophosphoric acid, p. 28.)

Various analyses of the percentages of the different elements or units in the molecule have been made by many investigators, and the results, though not identical, agree fairly well in many cases. Some of these analyses are given in the table :—

Investigator.	Source of Lecithin.	Percentage Composition.				Molecular Weight.	N : P Ratio.	Equivalent Empirical Formula.
		C.	H.	N.	P.			
Thudichum	Brain .	66·75	10·67	1·81	4·00	773	1 : 1·00	$C_{43}H_{84}NPO_8$
Erlandsen .	Heart .	65·70	10·21	1·79	3·95	785	1 : 1·00	$C_{45}H_{90}NPO_9$
MacLean .	,, .	66·27	10·17	1·87	3·95	—	1 : 1·05	—
Thierfelder and Stern	Egg yolk	64·63	10·96	1·79	3·95	771	1 : 1·00	$C_{42}H_{78}NPO_9$
Baskoff .	Liver .	64·64	10·71	1·95	4·00	—	1 : 1·08	—

For the estimation of nitrogen in lecithin and other lipins Kjeldahl's method gives good results, while for phosphorus determinations Neumann's [1902, 1904] process is very suitable [Freundler, 1912]. Owing to the presence of phosphoric acid in the molecule, complete combustion of these substances for carbon and hydrogen estimations is attended with some difficulty [Stern and Thierfelder, 1907]. Methods of estimating certain radicles of lecithin are given by Foster [1915]; the estimation of glycerol is described by Erlandsen [1907], Malengreau and Prigent [1912]; of choline by Erlandsen [1907], MacLean [1908], Levene and Ingvaldsen [1920]; of the fatty acids by Rollett [1909], Levene and Ingvaldsen [1920, 1], Levene and Simms [1921].

The agreement in the analytical figures is more or less accidental, for it will be shown that the lecithin analysed was in all cases (with the possible exception of Thudichum's sample) a mixture of true lecithin with another lecithin-like substance, which has now been identified as kephalin, and the empirical composition of which is not very different from that of lecithin [Maclean, 1915].

The constitution of lecithin has been worked out chiefly as the result of investigation of its hydrolytic products. On hydrolysis, lecithin yields glycerophosphoric acid, fatty acids and choline; the glycerophosphoric acid may be partly decomposed, giving glycerol and phosphoric acid.

Hydrolytic Products of Lecithin.

(*a*) *The Base.*

Assuming the structure given above for lecithin to be the correct one, it is obvious that the choline represents all the nitrogen of the molecule, so that the amount of choline present could be ascertained from the amount of nitrogen found on analysis. On quantitative estimation of the choline the amount found should agree with that of the nitrogen present. For a long time, however, the figures actually

obtained generally fell considerably below the theoretical values. Thus Heffter [1891], using lecithin extracted from liver, obtained only 25 per cent. of the theoretical amount of choline, while egg lecithin gave only 77 per cent. [Moruzzi, 1908], heart lecithin 42 per cent. [Erlandsen, 1907], and milk lecithin 39·5 per cent. [Osborne and Wakeman, 1915]. The statement of Coriat [1904] that he obtained theoretical choline values from brain lecithin prepared by Koch's method [1902] is contrary to the experience of all other observers. It is, however, interesting to note that a lecithin prepared from the cadmium chloride compound after the latter had been well washed with ether was found by Lüdecke [1905] to contain 96 per cent. of the theoretical amount of choline.

In the earlier work on lecithin not only was the theoretical yield of choline not obtained, but specimens prepared from different sources gave different amounts of base under similar conditions of experiment, although the samples of lecithin used were prepared and purified according to the best methods in use at the time, and all had a N : P ratio of approximately 1 : 1.

Some of these results are seen in the following table :—

Observer.	Source of Lecithin.	Reagent Employed in Hydrolysis.	Time of Boiling in Hours.	Percentage of Nitrogen Obtained as Choline Pt. Chloride. (Averages of several experiments given.)
MacLean [1908]	Commercial specimen "Lecithol" (Riedel)	Baryta in methyl alcohol	2 to 15	76 to 78
,, [1908]	Commercial specimen "Lecithol" (Riedel)	Baryta in H_2O	$2\frac{1}{2}$	76 ,, 78
,, [1908, 2]	Ox heart	,, ,, methyl alcohol	2 to 10	37·3 ,, 41·4
,, [1908, 2]	,, ,,	Baryta in H_2O	2 ,, 10	37 ,, 42
,, [1909]	Egg yolk	,, ,, methyl alcohol	3 ,, 6	65 ,, 66
,, [1909]	,, ,,	Hydrochloric acid	$1\frac{1}{2}$,, 5	64 ,, 65
,, [1915]	Ox heart	Sulphuric acid	30	52

It is interesting to observe that commercial lecithin gave the highest percentage of choline; in one sample (Kahlbaum's lecithin) as high a yield as 92 per cent. was obtained [MacLean, 1915]. From a similar specimen of lecithin even higher figures were found by Malengreau and Prigent [1912]. These trade lecithins are prepared from eggs, yet they generally show a much higher choline content than similar lecithins prepared from the same source in the laboratory. As will be

seen later, the explanation of this must depend on their method of purification, which is probably through the cadmium chloride compound (see p. 23).

In the experiments quoted no effect could be ascribed to the time during which the substance was subjected to hydrolysis. Boiling for two hours or for ten hours gave identical results [MacLean, 1908, 2]. The percentage of nitrogen obtained as choline platinochloride varied in the different specimens from 37 to 78 per cent.

This small yield of the base was not due to the destruction of choline by the barium hydroxide or acid used in hydrolysis, for it was shown that only very small traces of choline were destroyed under the conditions of the experiment [Gulewitsch, 1898; MacLean, 1908, 1]. MacLean [1909, 1909, 1] also showed that when choline was boiled for several hours with substances representing the hydrolytic products of lecithin, it was possible to recover the base in almost theoretical amount. It was evident that the low percentage of choline obtained from lecithin was not due to decomposition or to defects in the method for the estimation of choline.

Another point observed in these experiments was that the fatty acids or fatty acid soaps obtained on hydrolysis invariably contained a small amount of nitrogen [MacLean, 1908; 1908, 1]. It was found impossible to obtain nitrogen-free fatty acids, however much they were washed. The amount of this residual nitrogen was not large, but it was fairly constant, and amounted to about 5 to 6 per cent. of the nitrogen present in the original lecithin. These results have been corroborated by Trier [1913] and others. Their significance is not at all clear, but the amounts of nitrogen retained are not sufficient to account for more than a small fraction of the loss of choline in lecithin analysis.

The conclusion drawn from all these experiments was that the whole of the nitrogen of the lecithin under investigation was not represented by choline as indicated in the generally accepted lecithin formula, but that some other base was also present [MacLean, 1909, 1]. Since different lecithins gave different amounts of choline, and even lecithins obtained from the same source, but isolated by different methods (egg lecithin of commerce and egg lecithin obtained in the laboratory), gave varying amounts of this base, it was most reasonable to assume that lecithin was really a mixture of two substances of somewhat similar composition, one of them having choline as its base and the other some unknown nitrogenous body. The suggestion

of Darrah and MacArthur [1916], that lecithin is a combination containing one molecule of choline and one molecule of another base (amino-ethyl alcohol) was entirely contradicted by the fact that such variable amounts of choline were found in different samples of lecithin.

These suggestions, indicating that lecithin contained another base besides choline, were confirmed by the discovery of Trier [1911], who found β-amino-ethyl alcohol, $CH_2(NH_2)CH_2 . OH$ [see Barger, 1914], among the products of hydrolysis of the phospholipins of bean meal (*Phaseolus vulgaris*). Later, the same observer recovered amino-ethyl alcohol from egg lecithin, identifying it by means of the gold chloride combination [1912, 1; 1913]. Amino-ethyl alcohol was also discovered independently in egg lecithin by Eppler [1913] working in Thierfelder's laboratory, and has been found in several specimens of heart lecithin [MacLean, 1915]. It has also been obtained recently from various other lecithins both of animal and plant origin. Amino-ethyl alcohol is very difficult to estimate in the ordinary way, since all its compounds are exceedingly soluble, but it can be very easily estimated indirectly by Van Slyke's method for determining amino nitrogen [1912], since all its nitrogen is readily given off on treatment with nitrous acid. The application of this indirect method is, however, only justified if it is certain that no other base containing the amino-group occurs in the lipin molecule. All the amino nitrogen present in lecithin is probably present as amino-ethyl alcohol, since there is now abundant evidence that this base is always present, and no other base containing amino nitrogen has yet been obtained from lecithin. Thierfelder and Schulze [1915], however, suggest that a small amount of some other base is also present. From alcoholic solutions of hydrolysed lecithin, platinum chloride precipitates only choline; the salt formed by amino-ethyl alcohol with platinum chloride remains in solution. It was on account of the extreme solubility of the compounds of this base that it had been missed for so long. The presence of two bases in lecithin being established, it was now of interest to determine whether the whole of the nitrogen of lecithin could be accounted for by the choline and amino nitrogen present.[1]

[1] Since the quantitative estimation of amino-ethyl alcohol has been carried out by various observers indirectly by estimating the amino nitrogen, it is obvious that the results obtained do not exclude the possibility of some other amino substance being present.

Distribution of Lecithin Nitrogen as Choline and Amino-Ethyl Alcohol.

To determine whether lecithin might possibly contain some base other than the two mentioned, MacLean [1915] carried out experiments with hydrolysed and ordinary unhydrolysed lecithin. The choline was determined in the usual way as the platinum chloride compound, while the amino nitrogen was estimated by Van Slyke's method, using in the majority of cases his micro form of apparatus [1913].[1]

(*a*) *Experiments with Unhydrolysed Lecithin.*

Attempts to estimate the amino nitrogen in unhydrolysed lecithin were rendered difficult, partly on account of the frothing which resulted, and partly owing to the lack of a suitable solvent for lecithin. The solvent used was strong acetic acid, but it was found that after the preliminary shaking of the sodium nitrite and acetic acid, according to the directions of Van Slyke, the addition of acetic acid (instead of the usual aqueous solvent or very weak acid or alkali) acted in such a way as to give a good deal of gas which was not taken up by the permanganate absorbing mixture. This introduced an error which had to be allowed for by controls, but even then the results were not satisfactory. In spite of these disadvantages very suggestive numbers were obtained. The table shows the results of five experiments. The choline was estimated by hydrolysis of the lecithin with weak acid followed by the ordinary procedure:—

No.	Amino Nitrogen Found in Percentage of Total Nitrogen.	Choline Nitrogen Found in Percentage of Total Nitrogen.	Nitrogen Retained by Fatty Acids in Percentage of Total Nitrogen.	Percentage of Total Nitrogen Accounted for.
1	31·4	66	4	101·4
2	30	68·6	3	101·6
3	38·2	63	4·4	105·6
4	28	64	6	98
5	30	68	6	104

These results, though not conclusive, suggested that all the nitrogen of lecithin, not represented by choline, was present in the amino form—probably as amino-ethyl alcohol. This is better brought out in the next set of experiments, where hydrolysed lecithin was used for the amino nitrogen estimation and no experimental difficulties were encountered.

[1] See Plimmer's monograph, Part I, Analysis, 1917.

(*b*) *Experiments with Hydrolysed Lecithin.*

In these experiments hydrolysis was carried out with weak sulphuric or hydrochloric acid. For technical considerations it was found more convenient in some cases to estimate the choline in one portion of the lecithin, a separate portion of the same sample being used for the amino-ethyl alcohol determinations. This was done in two experiments. In other cases, aliquot parts of the same filtrate were taken. The amounts of nitrogen given are in terms of the total nitrogen in the filtrates obtained after hydrolysis:—

Experiment.	Source of Lecithin.	Total Nitrogen in Filtrate.	Percentage of Nitrogen as Choline.	Percentage of Nitrogen as Amino-Ethyl Alcohol.	Percentage of Total Nitrogen of Filtrate.
1	Egg yolk . .	17·5	74·6	25·7	100·3
2	„ „ . .	16·5	78·8	23·6	102·4
3	Ox heart . .	20·2	74·2	24·5	98·7
4	Horse kidney .	23	66·5	34·8	101·3
5	Egg yolk . .	—	66·4	35·8	102·2
6	„ „ . .	—	70·0	31·0	101·0

From these results there can be no doubt that the whole of the water-soluble nitrogen of the lecithin is present in the form of choline and an amino compound. It is probable that the nitrogen retained in the fatty acids was also in the amino form, though some of this might be due to traces of impurity in the lecithin; it is worth noting that in many cases the nitrogen content of the lecithin was often slightly higher than is required to give a N : P ratio of 1 : 1. At any rate, the part retained by the fatty acids is small.

When an alcoholic solution of choline containing amino-ethyl alcohol is precipitated by platinum chloride it frequently happens, if the solutions are concentrated, that some amino-ethyl alcohol platinum chloride is carried down with the choline double salt. This was found to be the case to a very slight extent in the above experiments. Here the amino nitrogen actually present in the platinum chloride precipitate was estimated and due allowance made. In this connexion, it is best not to have the alcoholic choline solution too concentrated; again, the precipitate should be very thoroughly washed with absolute alcohol before drying. It must be dried at 105° to remove water of crystallisation. In pure alcoholic solution, synthetic amino-ethyl alcohol gives a distinct precipitate with platinum chloride, especially if the latter is added in excess, but in the presence of glycerol and other impurities the double salt tends to remain in solution.

Separation of Lecithin into its Components.

So far it was not known definitely whether lecithin was a mixture of two phospholipins or a complicated compound containing two bases. Indeed, it was not proved that any body corresponding to the accepted lecithin formula really existed. MacLean [1915], however, succeeded in separating lecithin into its components and obtained two substances, one of which had all its nitrogen in the form of choline, and presumably possessed the formula ascribed to lecithin. The other substance present was not obtained in quite pure form, but was regarded as being almost certainly kephalin.

It will thus be seen that the term "lecithin," as hitherto employed, refers to a body which is soluble in alcohol, and which represents a mixture of pure lecithin and kephalin in varying proportions. The amount of kephalin present depends largely on the methods adopted in the preparation of the crude lecithin, but it may be said in a general way that the greater the precautions taken to obtain fresh material and to dry it rapidly, the more kephalin does the crude lecithin contain (Chapter III).

The method adopted for the separation of these two bodies depended on the different solubilities of the cadmium chloride compounds of lecithin and kephalin. MacLean [1909, 2] showed that when an alcoholic solution of crude lecithin is treated with cadmium chloride, the percentage of nitrogen present as choline in the lecithin precipitated as the cadmium chloride compound, is greater than that of the original lecithin; on the other hand, the substance remaining in the filtrate has correspondingly less of its nitrogen represented by choline.

This observation, which was confirmed by Trier [1912] and by Eppler [1913], suggested a possible method for the fractionation of lecithin into its components, but it was not found possible to effect complete separation by this means. By the use of ether, however, isolation of a true lecithin, containing only choline, was accomplished. The original lecithin was dissolved in alcohol, and excess of cadmium chloride added. The resulting precipitate was thoroughly digested with ether, which dissolved the kephalin part, leaving true lecithin cadmium chloride, behind as a white residue. This ether-insoluble compound was dissolved in a mixture of ethyl acetate and alcohol, from which it separated on cooling in the form of beautiful white clusters of well-formed needles arranged in stars and rosettes. In one case the ether-insoluble cadmium chloride compound was divided into two parts—a benzene-soluble and a benzene-insoluble part—before

treatment with the mixture of alcohol and ethyl acetate. Analysis showed that practically the whole of the nitrogen of the ether insoluble cadmium chloride combination was present as choline. In the experiment quoted the numbers refer to the total nitrogen of the filtrate after hydrolysis; no account is taken of the small amount of nitrogen retained by the fatty acids or other precipitate. The lecithin used was obtained from ox heart. The amino nitrogen was estimated in the filtrate after the separation of choline as the platinum salt.

No.	Substance.	Percentage Nitrogen as Choline.	Percentage Nitrogen in Amino Form.	Percentage of Total Filtrate Nitrogen Accounted for.
1	Lecithin	62	37·2	99·2
2	Cadmium chloride pp. from (1) . . .	65	33	98
3	Ether insoluble fraction of (2) (benzene-sol.)	94	3	97
4	,, ,, ,, (,, insol.)	99	None	99
5	,, soluble ,, (2) . . .	45	54	99

Here the two fractions (3) and (4) contained all their nitrogen (with the exception of a trace in No. 3) as choline. A cadmium chloride compound of a true lecithin, having all its nitrogen as choline, had therefore been separated from an original lecithin which had only 62 per cent. of its nitrogen as choline.

The presence of kephalin in the crude lecithin was confirmed by Levene and West [1918, 1, 2], who also succeeded in obtaining specimens of lecithin which were entirely free from amino nitrogen.

On separation of the free phospholipin by Bergell's method, from the cadmium chloride compound which had been well washed with ether [1900], a sample of pure lecithin was isolated; this closely resembled in its properties ordinary lecithin, and from it the theoretical amount of choline was obtained.

From the results of these experiments, lecithin as usually obtained must be regarded as a mixture of pure lecithin and kephalin, and the figures derived from analyses of lecithin which has not been freed from kephalin, though often in agreement with each other, are worthless as an indication of purity. The subject is discussed later in considering the methods employed for the preparation and isolation of lecithin (Chapter III).

Other Bases of Lecithin.

Besides the amino-ethyl alcohol and choline already discussed, several investigators have suggested that other bases might be present.

Thus Berlin (1912) states that homo-choline might possibly substitute choline in certain lecithins. So far no definite evidence of the presence of any other basic body has been produced, and it is probable that the indications obtained by Thierfelder and Schulze [1915] of the existence of another base in lecithin depended on the presence of impurities in the sample of lecithin employed.

(*b*) *The Fatty Acids of Lecithin.*

The formula assigned above to lecithin admits only of the presence of two fatty acid radicles in the molecule, but various observers have obtained three or even four different fatty acids among the hydrolytic products of lecithin, while others could find only one. Thus Diakonow [1868] stated that the only fatty acid present was stearic ($C_{18}H_{36}O_2$), while Strecker [1868] obtained palmitic acid ($C_{16}H_{32}O_2$) and oleic acid ($C_{18}H_{34}O_2$), but no stearic acid. Diakonow [1868, 3] attempted to explain these differences by assuming the existence of various lecithins, each containing different fatty acids. As proof of this assertion he stated that a sample of lecithin which was obtained in the form of a precipitate by cooling an alcoholic extract of egg yolk, gave only stearic acid. On the other hand, the filtrate from the cooled alcohol extract contained a lecithin which furnished both stearic and oleic acids. The first of these lecithins corresponded to distearyl lecithin, while the second one would be regarded as stearyl-oleyl lecithin. By a similar process of reasoning Strecker's palmitic acid was accounted for on the ground that the method of isolation adopted yielded a lecithin containing palmitic acid. Since observations on the iodine value of lecithin suggest that all lecithins contain at least one unsaturated acid, the existence of such a compound as distearyl lecithin is highly improbable. Stearic and oleic acids were found by Ulpiani [1901, 1], while Cousin [1903], using egg-yolk lecithin, obtained stearic, palmitic, oleic and linolic acids; from brain lecithin he isolated similar products, though he was unable to identify linolic acid with certainty [1906].

Other results include stearic, palmitic and oleic acids from brain lecithin [Koch, 1902] and from lecithin from ovaries and testicles of tunny fish [Dezani, 1909]. Palmitic and oleic acids from egg-yolk lecithin [Serano and Palazzi, 1911] and oleic, linolic and stearic acids from commercial lecithin [Fourneau and Piettre, 1912]. Ritter [1914] could obtain only stearic acid from lecithin reduced by the method of

Paal and Oehme [1913]. He concluded, therefore, that the acids of lecithin belonged entirely to the C_{18} series [see also Riedel, 1913, 1914].

It is obvious, however, that the results of the previous workers on the identification of the fatty acids of lecithin were vitiated by the nature of the material they used. In nearly all cases a mixture of lecithin and kephalin was employed, and it was therefore certain that part of the fatty acids obtained had been derived from kephalin. Thudichum [1884], who worked with a specimen of lecithin which from its method of preparation must have contained little or no kephalin, obtained oleic acid and an acid having the composition of the so-called margaric acid ($C_{17}H_{34}O_2$).[1]

With the exception of Diakonow, all observers were agreed that both saturated and unsaturated acids occur together in lecithin. The preparation of a lecithin derivative containing only a saturated acid was made in a very interesting way by Delezenne and his colleagues [Delezenne and Ledebt, 1912; Delezenne and Fourneau, 1914]. They found that cobra venom reacted with lecithin splitting off the unsaturated acid radicle and leaving a crystalline compound, from which only a saturated fatty acid could be isolated. By making use of this reaction a product was obtained from commercial egg lecithin which contained only palmitic acid, the unsaturated acid originally present in the lecithin molecule having been split off. Since this reaction appears to be a general one, it affords additional evidence that both saturated and unsaturated acid radicles constitute an essential part of the original lecithin molecule.

It is only recently that Levene and his colleagues have used pure lecithin free from kephalin as the starting material for their investigation of the nature of the fatty acids present. They have succeeded in showing that not only are both saturated and unsaturated acids present, but that they occur in equal proportions. The carefully purified cadmium chloride salt of lecithin washed entirely free from the corresponding kephalin compound by ether was hydrolysed with 10 per cent. HCl and the acids thus set free. Sufficient material was taken to allow of the separation of the saturated fatty acids by the fractional distillation of their methyl esters under diminished pressure; they were then identified by determination of their elementary composition, of their molecular weights, and by their melting-points. The unsaturated acids were separated in the usual manner by the solubility

[1] It is now recognised that the substance formally called margaric acid was not a chemical entity but probably a mixture of palmitic and stearic acids.

of their lead salts in ether, and were identified by their iodine numbers and by analyses of their bromides and the corresponding hydrogenated acids.

Samples of lecithin prepared from various sources have been investigated in this manner, and it has been conclusively shown that both palmitic and stearic acids occur in the lecithin derived from liver [Levene and Ingvaldsen, 1920, 1; Levene and Simms, 1921, 1922], brain [Levene and Rolf, 1921, 1; 1922, 2], egg yolk [Levene and Rolf, 1921, 1922] and soya bean [Levene and Rolf, 1925].

Oleic acid was also invariably present; in addition, another unsaturated acid was detected in lecithins from brain, liver and egg yolk. This was an acid containing twenty carbon atoms and four double bonds, known as arachidonic acid. It gave an octobromide insoluble in benzene, and was identical with the acid previously isolated by Hartley [1909] from pig's liver. In egg yolk linolic acid has been found in addition to oleic and traces of arachidonic acids [Levene and Rolf, 1921, 1922]; liver lecithin also contains linolenic acid.

At least four or five acids are present, therefore, in the samples of lecithin derived from the various organs. The proportion in which these acids are present varies, however, considerably in the different organs. In liver lecithin, for instance, a much larger proportion of more highly unsaturated acids is present than in the lecithin prepared from egg yolk. The iodine number of the cadmium chloride compound of liver lecithin varied from 59 to 84; the same compound prepared from egg yolk lecithin gave an iodine number of 30 to 54, not much more than half that of the former compound.

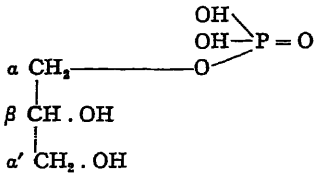
The work of Levene and his colleagues has enabled us to answer the question: Does more than one lecithin exist? A determination of the molecular weight has shown that lecithin contains not more than one molecular proportion of glycerophosphoric acid and two of fatty acids; since as many as five acids have been identified, it follows that several lecithins must exist, differing in the nature of their fatty acids, a suggestion put forward by Diakonow more than fifty years ago. In liver lecithin the form containing the more highly unsaturated acid predominates. It is a matter of great interest that the highly unsaturated arachidonic acid should now be shown to be present in lecithin obtained from liver, brain and egg yolk, and should predominate in the lecithin derived from the liver.

Levene's work has very much illuminated the question of the nature of the fatty acids present in the lecithin molecule, and if we

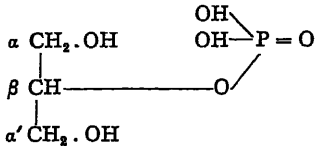
do not yet realise the full significance of these findings, an important step has been made to a better knowledge of the function of the lecithin molecule.

(c) *Glycerophosphoric Acid of Lecithin.*

From the chemical standpoint, this acid can exist in two modifications—the α- and β-forms—and is really the glycerol ester of phosphoric acid.



α-form (unsymmetrical).



β-form (symmetrical).

The α-form contains an asymmetric carbon atom, and is therefore capable of existing in optically active forms, whilst the β-variety is inactive. After the discovery of Willstätter [Willstätter and Lüdecke, 1904; Lüdecke, 1905; see also Mayer, 1906] that the glycerophosphoric acid of egg lecithin was optically active, rotating the plane of polarised light to the left, it was generally assumed that the glycerophosphoric acid of lecithin was the α-form. This observation of Willstätter, while proving the presence of α-glycerophosphoric acid in lecithin, did not exclude the possibility of some of the β-variety being present as well, and Tutin and Hann [1906] maintained that lecithin contained a mixture of α- and β-glycerophosphoric acids. The question was by no means easy to settle owing to the difficulties of identifying the two forms, but subsequently Grimbert and Bailly [1915; 1915, 1] introduced a simple chemical test, by means of which it was possible to determine whether these monoglycerophosphoric esters were of the α- or β-varieties. These observers pointed out that an α-ester, on careful oxidation so as to avoid hydrolysis, should yield a compound containing a ketone group which could be identified by Denigès' reaction [1909]. On the other hand, the β-form would not give this reaction. The oxidising agent used was a 0·25 per cent. solution of bromine in water; to prevent any hydrolysis by the nascent hydrogen bromide the reaction was carried out in the cold. By means of this test Bailly [1915, 1919] claimed to have shown that egg lecithin is a mixture of at least two isomers containing the symmetrical and asymmetrical varieties of glycerophosphoric acid. Indeed, he states that the inactive symmetrical form predominates.

The two acids may be separated by taking advantage of the difference in solubility of their sodium salts; if glycerophosphoric acid, obtained from lecithin, is neutralised with sodium carbonate, the crystalline sodium salt of β-glycerophosphoric acid may be separated, for it is much less soluble than the sodium salt of the α-acid. The mother liquor is then precipitated with calcium chloride, and the calcium salt of the α-acid precipitated and washed until it is free from glycerol. Both salts are inactive. So far, all the work that had been done on the glycero-phosphoric acid of lecithin had been carried out on material which we now know to be a mixture of pure lecithin and kephalin. Levene and Rolf [1919] repeated the work of Willstätter and Lüdecke, taking as their starting material a preparation of lecithin which was practically free from amino nitrogen, and which did not therefore contain any appreciable proportion of kephalin. They obtained a specimen of the barium salt of glycerophosphoric acid which, after a long process of purification showed an optical rotation $[\alpha]_D^{20} = -0{\cdot}74$. Willstätter and Lüdecke had found for their specimen $[\alpha]_D^{20} = -1{\cdot}71$, but they state that the magnitude of the rotation depended very much on the mode of preparation, a result confirmed by Levene and Rolf. It appears, therefore, to be definitely established that the lævo-rotatory form of α-glycerophosphoric acid does occur in true lecithin; Levene and Rolf did not, however, carry out the Denigès test on the glycerophosphate obtained from the pure lecithin, and their results are not inconsistent with the view of Bailly that both α- and β-glycerophosphoric acids are present in the lecithin molecule.

It is probable, therefore, that lecithin may contain a mixture of the α- and β-forms of glycerophosphoric acid; in many cases the product obtained on hydrolysis is optically inactive, and consists to some extent of the racemic form, but whether any of the dextro-rotatory form actually occurs as such in lecithin is unknown. Probably it does not.

From the hydrolytic products of Poulenc's commercial lecithin, Bailly [1919] was only able to obtain the β-form of glycerophosphoric acid. It has already been pointed out when discussing the nature of the base of lecithin that some of the commercial preparations of lecithin obtained from egg-yolk contain hardly any of their nitrogen in the amino form, and must therefore be almost free from kephalin. Bailly's result might be explained by assuming that the β-form of glycerophosphoric acid was derived from lecithin, and that the α-form

of glycerophosphoric acid was contained only in the kephalin molecule. This, however, cannot be the case; Levene and Rolf have probably worked with purer specimens of lecithin and kephalin than any other investigator, and their results seem to establish conclusively that both lecithin and kephalin contain the lævo-rotatory form of α-glycerophosphoric acid.

According to Malengreau and Prigent [1912] lecithin glycerophosphoric acid is fairly resistant to acids, and is more readily hydrolysed by acids in weak concentration than by stronger solutions. It is readily decomposed by a ferment present in the intestines, kidneys, and other tissues [Grossler and Husler, 1912].

Though the literature on the naturally occurring glycerophosphoric acid is comparatively small, much work has been done on the synthetic product. For the chief results obtained in this connexion, in addition to references already given, the following may be mentioned: Adrian and Trillat [1898], Carre [1904; 1912; 1912, 1], Power and Tutin [1905], Malengreau and Prigent [1911], Neuberg and Tir [1911], Neuberg and Kretschmer [1911], Contardi [1912], Rogier and Fiore [1913], King and Pyman [1914], Bailly [1915, 1; 1921].

Our knowledge of the constitution of lecithin may then be summarised as follows:—

The term lecithin denotes a compound of the base choline with the glycerophosphoric acid radicle and with one saturated and one unsaturated fatty acid radicle.

A number of different lecithins exist, all characterised by the presence of choline as the base built up into the molecule. In some lecithins the glycerophosphoric acid present is the lævo-rotatory form of the α-acid; in others it is possible that the symmetrical β-acid may exist. The purest specimen of lecithin which has yet been prepared is probably a mixture of these two forms. A number of individual lecithins occur characterised by the presence of different fatty acid radicles, one of which must, however, be saturated and one unsaturated. Lecithins containing either palmitic or stearic as the saturated, and either oleic or arachidonic as the unsaturated, acid are known, but these always occur together, and no method of separating them into individual lecithins has been found. Only in egg-yolk lecithin has a third unsaturated acid been identified. Although much work still remains to be done in separating the mixtures of lecithins occurring in the different tissues, it is obvious that great progress has been made during the last fifteen years in unravelling the constitution of these complex substances.

ATTEMPTS AT SYNTHESIS OF LECITHIN.

For such a complicated product as lecithin it is obvious that a more complete knowledge of its constitution than we at present possess must precede all successful endeavours to synthesise it. The old idea that lecithin represented a choline ester of a distearylphosphoric acid formed the basis, in a few cases, for attempts at synthesis of this product. Up to the present, the results have not been satisfactory, though certain claims have been advanced.

The first important work in this connexion was carried out by Hundeshagen [1883], who by treating distearylphosphoric acid with choline carbonate obtained a choline-distearylglycerophosphate. Here the choline reacted as a substituted ammonium base, so that the product was a choline salt and not an ester compound, as in the case of lecithin.

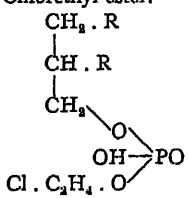
$$\begin{array}{l} \alpha\ CH_2(O \cdot CO \cdot C_{17}H_{35}) \\ \beta\ CH(O \cdot CO \cdot C_{17}H_{35}) \\ \alpha'\ CH_2 \cdot O \cdot PO(OH)_2 - N(CH_3)_3 \cdot C_2H_4 \cdot OH \end{array}$$

Hundeshagen prepared his distearin by Berthelot's method [1854], and by heating this with phosphoric anhydride he obtained distearylglycerophosphoric acid. Since Berthelot's method gives chiefly α, α'-distearin [Grün, 1905], it is probable that Hundeshagen's product was largely or altogether composed of the choline derivative of this compound. All attempts to combine the choline in ester form failed.

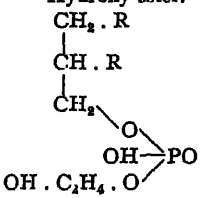
Gilson [1888] endeavoured to overcome this difficulty by treating distearylphosphoric acid with ethylene oxide and trimethylamine, but here also the result was unsatisfactory.

The problem was recently taken up by Grün and Kade [1912; 1912, I], who treated distearin with phosphorus pentoxide and glycol chlorhydrin. The resulting product consisted of a mixture of two esters—an hydroxyethyl ester and a chlorethyl ester—formed respectively by the interaction of the $CH_2 \cdot Cl$ and the $CH_2 \cdot OH$ groups of chlorhydrin with the phosphoric acid :—

Chlorethyl ester.

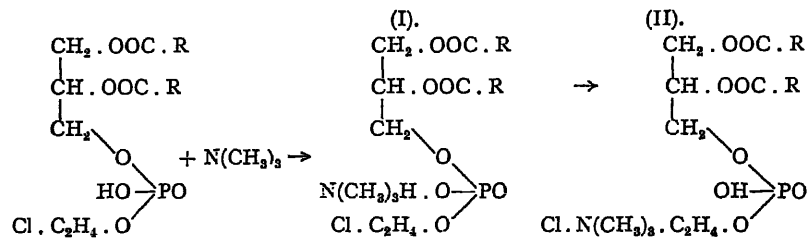


Hydroxy ester.



By heating the product with thionyl chloride the hydroxyethyl ester was converted into the chlorethyl ester, so that a single substance resulted.

This chlorethyl ester was then treated with trimethylamine, the first stage in the reaction being the formation of the trimethylammonium salt of chlorethylphosphoric acid (I), which in the presence of excess of trimethylamine was converted into the choline chloride ester of distearylphosphoric acid (II) (lecithin chloride).



About 1·5 gms. of this compound were obtained, but though the analysis, as far as it went, appeared to agree fairly well with that required by the theory, the authors do not seem to be quite satisfied that the compound obtained was actually pure lecithin chloride as represented by the above formula. It is interesting to observe that this product agreed with lecithin in its general solubility in many organic solvents.

Experiments to convert the chlorethyl ester of phosphoric acid into the choline ester by the action of trimethylamine were first carried out by Langheld [1911]. He studied the reaction of ethyl metaphosphate with chlorhydrin, and obtained the ethyl chlorethyl ester of orthophosphoric acid. This substance on treatment with trimethylamine gave a product choline ethyl phosphate, the choline being attached in ester form. No attempts to combine this with distearin in order to form a product similar to lecithin were carried out.

By acting on lysolecithin (see p. 38) with sodium acetate and the appropriate acid anhydride, Levene and Rolf [1924] have synthesised lecithins containing the stearyl or palmityl radicle and one of the four radicles, acetyl, benzoyl, oleyl or elaidyl. These synthetic lecithins were free from haemolytic properties.

The physical properties of naturally occurring lecithin appear to be due to the presence of the more highly unsaturated acids, for the properties of oleyl lecithin are intermediate between the properties of reduced lecithin and those of the more highly unsaturated lecithins occurring naturally.

CHIEF PROPERTIES OF LECITHIN.

Freshly prepared lecithin is a yellowish-white waxy substance, which on exposure to air absorbs oxygen and soon assumes a dark brown colour. It is very hygroscopic, and in the presence of moisture forms a soft plastic mass. On thoroughly drying *in vacuo* it becomes hard and somewhat brittle, so that it can be ground to a coarse powder.

The so-called melting-point of lecithin is indefinite, but is somewhere in the region of 60°; at 110° it decomposes and forms a brown mass.

Lecithin prepared at the ordinary temperature as well as the corresponding cadmium chloride compounds are dextro-rotatory. By heating an alcoholic lecithin solution at 90° to 100° in a closed tube for some time, the optically active body becomes inactive.

Lecithin dissolves very easily in alcohol, ether, chloroform, benzene, petroleum ether and many other organic reagents; also in aqueous solutions of bile salts [Long and Gephart, 1908, 1]. With some of these solvents it forms true solutions, while in the case of others the solutions are probably colloidal [Loewe, 1912, 3]. In acetone and methyl acetate it is insoluble. In contact with water it swells up and ultimately, if sufficient fluid is present, forms a slimy emulsion or colloidal solution from which it can be readily precipitated by salts with divalent cations, such as calcium and magnesium [Koch, 1903, 1907, 1909; Porges and Neubauer, 1907]; salts containing monovalent cations (NaCl, etc.) also act in the same way, but more slowly [Long and Gephart, 1908]. In the presence of a small amount of sodium chloride, acetone readily precipitates lecithin from its emulsions with water [MacLean, 1912; 1912, 3]. It is also readily precipitated from ether or chloroform solution by this reagent; from alcoholic solution acetone precipitates it in many cases rather slowly and incompletely. Separation of lecithin from ether solution is complete in the presence of a small amount of magnesium chloride [Nerking, 1910]. All the precipitations are apparently hastened by the presence of traces of neutral salts. Though insoluble in pure acetone, lecithin may dissolve to some extent in acetone containing fat or fatty acids, so that its separation from other fatty bodies by means of acetone is always incomplete.

Electrolytes decrease both the osmotic pressure and viscosity of aqueous lecithin suspensions, while lipin solvents, on the other hand, increase both [Handovsky and Wagner, 1911; Berczeller, 1914; Thomas, 1915].

Investigation of the distribution of dyes (methylene blue) between an aqueous phase and a chloroform phase, in which lecithin and various other lipins were dissolved, indicated that the distribution of the dye did not obey Henry's law, but appeared to follow the formula introduced by Freundlich for adsorption phenomena [Loewe, 1912].

Lecithin owes many of its chief properties to its colloidal nature. When shaken with chloroform, a lecithin emulsion becomes opalescent, due to adsorption of the chloroform [Calugareanu, 1910]. When added to a solution of albumoses part of the albumose is precipitated in the form of an adsorption compound. This and other reactions of lecithin with proteins and enzymes occur in exactly the same way when lecithin is replaced by mastic, showing that the phenomena are all directly dependent on the colloid nature of lecithin [Michaelis and Pincussohn, 1906; Michaelis and Rona, 1907].

Combinations of protein with lecithin such as vitellin and lecith-albumin are recognised, though our knowledge of these substances is as yet incomplete [Liebermann, 1893; Christen, 1905; Galeotti and Giampalmo, 1908; Mackenzie-Wallis and Schölberg, 1910; Handovsky and Wagner, 1911; Feinschmidt, 1912].

It is probable that the greater part of the lecithin of tissues exists in some kind of combination with protein. Inorganic material has also been found in lecithin, but it is improbable that this was present in true combination. Such inorganic substances are iron [Glikin, 1908; Burow, 1910; Altschul, 1912], calcium and chlorine [Stern and Thierfelder, 1907].

Several products containing sugar and lecithin occur in nature or have been prepared artificially (see Jecorin, p. 146), but it is probable that these are adsorption complexes; no definite combination between lecithin and carbohydrate in the chemical sense has been established, though Scott [1916] obtained indications that such combinations may possibly exist. According to Porges and Neubauer [1907], the power of lecithin to make ether-insoluble substances, such as sugar, soluble in ether is due to the fact that it is a hydrophile colloid, and so combines with water, and in this way takes up certain water-soluble substances.

Lecithin does not generally act as a true solvent, but rather as an adsorbent [Loewe, 1912, 2]. Many protein colloids which dissolve only in water are readily soluble in organic solutions, such as chloroform when lecithin is present [Michaelis and Rona, 1907].

Combinations of lecithin with glucosides and alkaloids [Bing,

1901], cholesterol and pigments [Overton, 1900], and enzymes [Michaelis and Rona, 1907] have been described, but all of them are insufficiently studied.

In many cases it is difficult to say whether we are dealing with true compounds of lecithin, adsorption complexes, or merely mechanical mixtures. Probably the majority of the so-called combinations are adsorption compounds [Loewe, 1912, 1].

Leathes [1923] has investigated the power of lecithin to form a film on the surface of water, using Adam's method [1922]; like the fatty acids, lecithin spreads itself on the surface of water, forming a film one molecule in thickness: the area occupied by each fatty chain under a pressure of 1·4 dynes per centimetre was measured and compared with that occupied by each fatty chain in a specimen of reduced lecithin. In the latter, the area occupied by the fatty acid chain is only about half that occupied by the corresponding chain in the unreduced lecithin. It appears, therefore, that the power which lecithin shows of forming an " expanded " film is connected with the presence of the unsaturated fatty acid radicle contained in it.

Lecithin shows the peculiar property of budding and growing out into the so-called myelin forms when placed in contact with water [Leathes, 1925].

Like various other lipins, lecithin forms " liquid crystals " [Lehmann, 1914].

Lecithin combines with acids and bases. Bing [1901] describes a NaCl-lecithin which is soluble in ether but insoluble in alcohol, and is precipitated from ethereal solution by alcohol. Addition compounds of lecithin with certain salts of the heavy metals, such as cadmium chloride, platinum chloride and mercuric chloride are well known. Lecithin-cadmium-chloride is almost insoluble in alcohol, but dissolves in a mixture of carbon disulphide and ether or alcohol. Analyses of this combination by various observers have yielded different figures for the cadmium content, but this was obviously dependent on the nature of the lecithin used, on the amount of washing with ether or other solvents, and on other factors. Indeed, such divergent results were just what might have been expected in the case of a variable mixture like lecithin. Both platinum chloride and mercuric chloride salts are insoluble in alcohol but soluble in ether. A molybdenum compound is also described [Ehrenfeld, 1908]. Lecithin is not precipitated from its alcoholic solution by lead acetate and ammonia [Thudichum, 1884].

Compounds of lecithin with salts of organic acids such as sodium lactate and potassium oxalate are also known.

On treatment with alkalies or acids [Moruzzi, 1908; MacLean, 1908] it is quickly hydrolysed on heating and more slowly in the cold; it is slowly decomposed by picric acid at room temperature [Lüdecke, 1905]. Various enzymes also decompose it [Bergell, 1901].

Lecithin is very labile, and undergoes changes as the result of oxidation, gradually becoming insoluble in alcohol and in ether and tending to become soluble in water. A highly oxidised specimen of lecithin may therefore differ materially from a fresh specimen in solubility and other properties, and no doubt this phenomenon accounts for certain alleged new varieties of lecithin which have been described.

This tendency to oxidation makes it necessary to adopt certain precautions when working with lecithin. Air and light should be excluded as far as possible, and the reagents employed should be quite pure [Erlandsen, 1907; Heubner, 1908; Stern and Thierfelder, 1907, etc.]. Lecithin should be preserved *in vacuo* in a dark desiccator, and all operations completed in the minimum time. This liability of lecithin to oxidation is dependent on the presence of unsaturated fatty acids in the molecule, and is much increased by the presence of various chemical reagents, such as iron salts [Thunberg, 1909, 1913; Warburg, 1913; Warburg and Meyerhof, 1913], potassium dichromate [Thunberg, 1916], and magnesium and manganese compounds [Ciaccio, 1915]. The absorption of oxygen by the lipins of the spinal cord has been demonstrated by means of the micro-spirometer [Signorelli, 1910]. According to Long [1908] an emulsion of lecithin in aqueous solution is fairly stable, but this statement must be accepted with reserve.

Lecithin absorbs iodine and bromine, and saturated halogen [1] derivatives of lecithin have been described [Riedel, 1905]. The "iodine value," which serves as a good indication of the degree of desaturation of the fatty acids present, also gives useful information as to the extent to which oxidation has taken place. The lowering of the iodine value consequent on oxidation accounts largely for the different results obtained by various observers. Thus for egg lecithin Rollett [1909] found a value of 69, while Stern and Thierfelder [1907] obtained only 48·7 for their specimens. Among other figures recorded are 100 for heart lecithin (Erlandsen), 63 for liver lecithin (Baskoff), while Cruickshank [1914] obtained for lecithin from ox heart 72, from liver 81, from testicles 117, and from thyroid 69.

[1] See "Actien Gesellschaft für Anilin Fabrikation" (1905).

It has, however, been definitely established by Levene and Rolf 1922; 1922, 1; 1922, 2] that four different unsaturated fatty acids occur in the various specimens of lecithin obtained from different sources, containing respectively four, three, two and one double bonds; since the proportion of these varies considerably in different specimens, and since we are not dealing with individual substances, but with a mixture of lecithins, constant iodine values cannot be expected.

Bromolecithins containing respectively two, four and six bromine atoms have recently been prepared by Levene and Rolf from the lecithins of soya bean [1925, 1]; di-, tetra-, and octobromo lecithins were isolated from the action of bromine on egg yolk [1926], but the liver lecithins gave di-, hexa-, and octobromo derivatives.

A number of colour reactions depending on the presence of unsaturated fatty acids have been described [Thudichum, 1884; Struve, 1900; Casavona, 1911].

The Action of Enzymes on Lecithin.

Lecithin is acted upon by lipases and split into glycerophosphoric acid, choline and fatty acids. Bokay [1877] investigated the action of the lipase of the intestinal juice, and Schumoff-Simanowski and Sieber [1906] examined the lipase from ricinus: in both cases the action was similar. Paul Meyer [1906] showed that steapsin acts only on the dextro form of lecithin, for he succeeded in obtaining inactive racemic lecithin by heating ordinary dextro-lecithin with alcohol in a sealed tube for from five to six hours at 90° to 100°. On treating the inactive product with steapsin he obtained a lævo-rotatory solution, the dextro form being broken down by the enzyme. The accuracy of this observation is, however, contested by Bang [1907]. The effect of lecithin on the action of the digestive ferments has been studied amongst others by Kuttner [1907], Neumann [1908], Centanni [1910], Lapidus [1910], and Minami [1912], but in no case has pure lecithin been used.

DERIVATIVES OF LECITHIN.

(*a*) *Lysolecithin.*

The existence of lysolecithin was first described by Delezenne and Fourneau [1914; cp. Delezenne and Ledebt, 1911; 1911, I; 1912]; it was obtained as a product of the reaction of cobra venom on a solution of lecithin. An enzyme is apparently present in the venom, which splits off the unsaturated acid from the lecithin molecule, leaving a well-defined crystalline compound containing only a saturated fatty acid radicle. It possesses powerful hæmolytic properties, which will be referred to again later (cp. Chapter VII).

It may be prepared by digesting the yolks of two eggs made up to 100 c.c. with physiological saline solution with 1 milligram of cobra venom. The digestion is carried on at 50° for twelve hours, the product evaporated under diminished pressure, and extracted with cold acetone. The residue is dissolved in absolute alcohol from which the crude lyso-compound is precipitated by ether. It is finally recrystallised many times from alcohol and from chloroform [Fourneau, 1920].

Levene and his colleagues [Levene and Rolf, 1923; Levene, Rolf and Simms, 1924] subsequently showed that the substance prepared in this way could be separated into two constituents. The crude material was converted into the cadmium chloride compound; the latter was purified and the base again liberated from it. A considerable amount of the less soluble constituent, lysokephalin, can be separated out from the chloroform solution, and, finally, by the fractional precipitation of the cadmium chloride salts, the lysolecithin was prepared quite free from amino nitrogen. Thus obtained, lysolecithin is a white hygroscopic substance, crystallising in needles; it is soluble in chloroform, alcohol and glacial acetic acid, insoluble in acetone and ether. With water it forms an emulsion, the addition of alkali causing immediate solution. On heating, it softens at 100°, and melts at the same time, decomposing at 263°. Its optical rotation is in chloroform $\alpha_D = -2{\cdot}6$, in glacial acetic acid $\alpha_D = +0{\cdot}8$. Like other amino acids, it has two dissociation constants, $K_1 = 0{\cdot}18$ and $K_2 = 1{\cdot}3 \times 10^{-12}$, the isoelectric range lying between pH 2·75 and 9·90. When lysolecithin is hydrolysed, palmitic and stearic acids are set free, an interesting confirmation of the existence of these acids in lecithin itself.

The cobralecithide previously obtained by Kyes [1903] appears to have been a mixture of crude lysolecithin, unchanged lecithin and venom [Fourneau, 1920].

(*b*) *Reduced Lecithin.*

Various attempts have been made to reduce lecithin by saturating it with hydrogen in the presence of a suitable catalyst, and so to prevent, as far as possible, oxidation of the unsaturated acids. Paal and Oehme [1913] reduced egg lecithin by saturating a solution of this substance in 90 per cent. alcohol with hydrogen in the presence of colloidal palladium. The resulting product was found to be a crystalline substance which was much less soluble in alcohol than was ordinary lecithin, and which could be recrystallised from hot alcohol. On hydrolysis this saturated lecithin furnished chiefly stearic with palmitic and probably myristic acids. Ritter [1914] the following year obtained a product from which the only acid isolated on hydrolysis was stearic. In both the above cases the substance used was a mixture of lecithin and kephalin. Levene and West [1918] worked with a crude lecithin containing a mixture of 20 per cent. kephalin and 80 per cent. lecithin, and noted that the addition of a few drops of acetic acid to the alcoholic solution facilitated the reduction. Their resulting product was crystallised from methyl ethyl ketone; it softened about 80°, and was completely melted at 235°. The optical activity was determined in chloroform solution $\alpha_D = +5{\cdot}4$. One sample obtained consisted of 94 per cent. of true hydrolecithin, only 6 per cent. of nitrogen being in the amino form. The only acid identified in the products of hydrolysis was stearic acid.

The properties of the reduced lecithin show considerable similarities with those of the lysolecithin described above.

KEPHALIN.

Kephalin is a phospholipin in many respects closely resembling lecithin, with which it seems to be associated in all tissues [Koch and Woods, 1905]. It is distinguished from lecithin by its insolubility in alcohol; the separation of lecithin and kephalin from a mixture of both lipins is based on this property.

Kephalin was first investigated by Thudichum [1884], who isolated it from a brain extract and suggested its probable composition. There is no doubt that Thudichum's sample was impure, but although the methods of isolating and purifying kephalin have since been greatly improved, it is still doubtful whether a chemically pure specimen has been obtained.

As the result of hydrolysis of kephalin, Thudichum found that it contained two fatty acids: (1) an acid identical with, or resembling, stearic acid which differed in different specimens of kephalin; and (2) a special acid which he considered peculiar to kephalin, and called kephalic acid. He also isolated glycerophosphoric acid and three basic bodies:—

(1) Choline (which he always refers to as "neurin").[1]

(2) A body which formed a compound with platinum chloride of the composition $(C_2H_7NO)_2(HCl)_2PtCl_4$, and to which he ascribed the formula

$$\left.\begin{matrix} C_2H_5O \\ H \\ H \end{matrix}\right\} N.$$

This body could be regarded either as "dimethylamine, in which the third atom of H is replaced by (OH), or as oxyethylamine simply." This product is now generally referred to as amino-ethyl alcohol, $NH_2 . CH_2 . CH_2OH$.

(3) A base whose platinum salt corresponded to the formula $C_5N_{14}N_2O . HCl . PtCl_4$.

Thudichum considered that the essential base of kephalin was choline, and that the amino-ethyl alcohol and the other base mentioned were merely secondary products formed from choline.

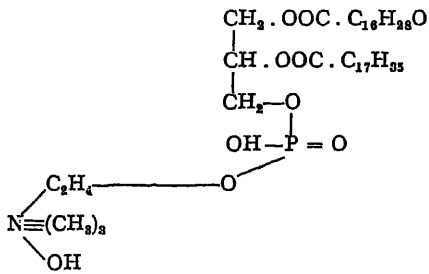
[1] In describing the base of both kephalin and lecithin, Thudichum gives the correct formula for choline platinum chloride $(C_5H_{13}NO)_2(HCl)_2PtCl_4$. From this Thudichum deduced that the free base was represented by $C_5H_{13}NO$—the formula for neurin. The reason for this is not very clear; probably he did not realise that these bases belonged to the type of ammonium hydroxide compounds, but regarded them as containing trivalent nitrogen. In this monograph Thudichum's "neurin" is always referred to as choline.

In the light of these results, he regarded the constitution of kephalin as analogous to that generally accepted for lecithin. The principal kephalins always contained stearic acid, and for such a kephalin he suggested the formula—

Kephalin (Thudichum).

$$C_3H_5\begin{cases}C_{17}H_{28}O_2 \text{ Kephalic acid radicle.}\\ C_{18}H_{35}O_2 \text{ Stearic acid radicle}\\ HO(OPO)C_5H_{12}NO.\end{cases}$$

This is similar to the lecithin formula already described, with the exception that kephalic acid is present here. This analogy is plainly brought out when the above formula is written like that given for lecithin :—[1]



Just as in the case of lecithin, Thudichum suggested an alternate formula in which the acid and glycerol radicles were directly attached to the phosphorus by substitution of the (OH) groups of phosphoric acid, " the base replacing an (OH) in glycerol, and being thus the earliest to be detached by hydrolysis."

Phosphoric Acid.

$$OP\begin{cases}OH\\ OH\\ OH\end{cases}$$

Kephalin.

$$OP\begin{cases}C_{17}H_{28}O_2 \text{ Kephalic acid radicle.}\\ C_{18}H_{35}O_2 \text{ Stearic } \quad ,, \quad ,,\\ C_3H_7O_3 \text{ Glycerol radicle.}\\ C_5H_{11}ON \text{ Choline}^2 \quad ,,\end{cases}$$

This hypothesis seemed to be substantiated by the fact that an intermediate product of hydrolysis was found which Thudichum called kephalophosphoric acid. This substance he considered to be composed of three acid radicles and one alcohol radicle.

$$OP\begin{cases}\text{Kephalic acid radicle.}\\ \text{Stearic } \quad ,, \quad ,,\\ \text{Glycerol radicle.}\end{cases}$$

This observation is of importance, since different observers are agreed that complete hydrolysis of kephalin is carried out with great difficulty, the fatty acids tending to retain a considerable amount of

[1] See footnote on opposite page.

[2] *Ibid.*

phosphorus. Kephalin in this respect differs from lecithin, which is hydrolysed with comparative ease [Erlandsen, 1907].

While certain of Thudichum's observations with regard to the radicles of kephalin were found to be erroneous by subsequent investigators, his general conception of the nature of the constituents of this body proved to be correct. We now recognise that kephalin contains two fatty acids—one saturated and the other unsaturated (Thudichum's kephalic acid)—also a basic body (Thudichum's oxyethylamine) as well as glycerol and phosphoric acid: the latter two substances are combined as glycerophosphoric acid.

Hydrolytic Products of Kephalin.

(*a*) *The Base.*

Thudichum's assumption that choline was the essential base of kephalin, and that the other bases found by him (amino-ethyl alcohol and a third ill-defined body) were decomposition products of choline, has been proved to be wrong. In a preparation of kephalin from sheep's brain, Koch [1902] could obtain no evidence of choline. On the contrary, he isolated from the products of hydrolysis a small amount of a platinum salt, which seemed to be a monomethyl-oxyethylamine compound; unfortunately, the quantity of substance at his disposal was too small for further purification. As the result of treating kephalin with hydriodic acid, he obtained evidence that the base was a methyl compound in which each nitrogen atom was attached to only one methyl group. It would appear, however, that Koch's results were due to the presence of glycerol in the molecule, and did not really give any information regarding the nature of the base. Cousin [1907], working with ox-brain kephalin, found choline and no other base. He also took the view that Thudichum's other bases were decomposition products. Fränkel and Neubauer [1909], who carried out investigations on three different specimens of kephalin, were unable to find any choline, but substantiated Koch's conclusion that kephalin contained one methyl group attached to each atom of nitrogen. Consideration of their experimental data hardly seems to justify their conclusion.

The subject was then investigated by Parnas and his co-workers [Baumann, 1913; Renall, 1913], who definitely showed that the base of kephalin is amino-ethyl alcohol ($NH_2 . CH_2 . CH_2OH$), and who found no evidence of the presence of another substance containing

nitrogen. These investigators showed that all the nitrogen of kephalin exists in the form of a primary amino base, and could be quantitatively estimated by the method described by Van Slyke [1912].[1] The base was also isolated in the form of the gold salt and identified by analysis. MacArthur [1914] claimed to have shown that amino-ethyl alcohol accounted for but a comparatively small amount of the total nitrogen of kephalin. According to this observer, kephalin nitrogen is present in four forms :—

(1) Ammonia nitrogen = 0·2 per cent.[2]
(2) Residual ,, = 0·2 ,, ,,
(3) Amino-ethyl alcohol nitrogen = 0·8 per cent.
(4) Amino acid nitrogen = 0·4 ,, ,,

The large amount of amino acid nitrogen found is striking ; MacArthur concludes that kephalin as ordinarily obtained is a mixture of two kephalins, one of which contains almost the whole of its nitrogen as amino-ethyl alcohol, while the nitrogen of the other is present in the form of an amino acid radicle.

While practically all observers are agreed that amino-ethyl alcohol is the characteristic base of kephalin, the percentage of this base present in any specimen of kephalin is generally calculated from a determination of the amount of amino-nitrogen present in the sample. In most cases, therefore, the possibility of the existence of amino compounds, other than amino-ethyl alcohol, is not excluded. So far there is no confirmation of MacArthur's work, but the existence of a second kephalin having its base in the form of an amino acid radicle must be considered as a possibility which is not yet disproved.

(*b*) *The Fatty Acids of Kephalin.*

(*A*) *Saturated Fatty Acid.*

In addition to the ordinary stearic acid which Thudichum found in the principal kephalins, he claimed that other kephalins existed in small amount which did not contain stearic acid, but an acid probably analogous with stearic acid, though of lower fusing-point, or an acid not homologous with stearic acid, and giving a lead compound soluble in ether. He thus postulated the existence of such varieties of kephalin as stearyl-kephalin, palmityl-kephalin and margaryl-kephalin.

[1] See Plimmer's " Chemical Constitution of the Proteins," Part I, Analysis, 1917.

[2] The percentages given are calculated on the weight of kephalin taken. They add up to 1·6 per cent., which roughly represents the percentage of nitrogen in kephalin.

The source of Thudichum's kephalin is not quite clear; it was all obtained from brain and chiefly from human brain, but that ox brain was also used appears possible. Cousin [1906] subsequently investigated this problem of the fatty acids of kephalin, and succeeded in isolating only one saturated acid (stearic acid) from ox-brain kephalin, though he obtained evidence of the presence of traces of lower saturated acids.

Fränkel and Dimitz [1909], working with kephalin prepared from human brains, stated that the substance contained two homologous kephalins, one of which furnished stearic acid and the other palmitic acid; the palmityl-kephalin predominated. These conclusions of Fränkel and Dimitz are based chiefly on the result of analyses of a lead compound of high molecular weight, which gave figures corresponding to a mixture of the two acids. Though it is claimed that these acids were actually obtained by fractional crystallisation from the mixture, no data beyond melting-points are furnished; obviously the melting-point of a body which has crystallised from a mixture of fatty acids cannot be regarded as any criterion of its purity unless substantiated by analytical figures. Further, as pointed out by Parnas [1909], oxyacids were probably present in the mixture. Thus the evidence for the conclusions of Fränkel and Dimitz is unsatisfactory. Parnas, in a very careful investigation of kephalin from human brain, isolated a fatty acid which on analysis proved to be pure stearic acid; he also showed that no other saturated acid was present. Later [1913] he again investigated the subject and reaffirmed his former results. Levene and West [1913, 2] came to similar conclusions; they examined four different specimens of brain kephalin and found only one saturated acid—stearic acid. At present, therefore, the evidence points to the conclusion that the only saturated acid found in kephalin prepared from human brain is stearic acid. This acid has also been found by MacArthur and Burton [1916].

(*B*) *The Unsaturated Fatty Acids of Kephalin.*

Besides saturated fatty acids, Thudichum recognised the presence of a special fatty acid in kephalin which he named "kephalic acid." Obviously, the acid was obtained in an impure state, and had probably undergone partial oxidation, but Thudichum indicated certain of its peculiarities, and concluded that it belonged to a series of acids containing at least one atom of oxygen more than the ordinary fatty acids.

Analyses of its barium salts gave different formulæ, $C_{19}H_{31}O_3$, $C_{17}H_{30}O_3$, and $C_{17}H_{28}O_3$. While in certain of its properties it failed to comply with the ordinary tests of purity, yet Thudichum regarded it as a chemical unit on account of the pertinacity with which it retained its properties and composition under most varied and severe treatment. The large amount obtained suggested that this body constituted an important part of the kephalin molecule. Thudichum, however, failed to recognise the essential nature of this acid, probably because of the oxidation changes which it had undergone, but concluded that it constituted the essential part of all kephalins. Kephalic acid, according to him, was the part of the kephalin molecule which bestowed on kephalin its characteristic properties. Kephalin might, therefore, be regarded as a lecithin in which one acid (oleic acid ?) was substituted by the special kephalic acid. Besides kephalic acid, Thudichum also obtained small amounts of another body, which was probably oleic acid, though he did not recognise it as such.

Koch [1903] found that kephalin absorbed iodine, and concluded that it contained an unsaturated acid. This observation was confirmed by Cousin [1906, 1907], who estimated the iodine values of the fluid fatty acids obtained from kephalin. From the high iodine values found and the results of analyses, Cousin identified the presence of an unsaturated acid containing two double bonds and belonging to the linolic acid series ($C_{18}H_{32}O_2$).

Falk [1908] oxidised the so-called kephalic acid with permanganate, and obtained a small amount of a substance to which he gave the probable formula $C_{18}H_{36}O_4$.

Parnas [1909] partially hydrolysed some brain kephalin with baryta, and isolated an intermediate product which contained acids and phosphorus, but was free from nitrogen. On further hydrolysis of this product with sodium hydroxide, a yellow oil was ultimately obtained, constituting about 18 per cent. of the original kephalin. This substance was transformed into the methyl ester, which on saturation with hydrogen in the presence of palladium gave the methyl ester of stearic acid melting at 69°. On saponification of the unsaturated methyl ester a light yellowish oil was obtained, which on analysis gave the formula $C_{18}H_{32}O_2$ (linolic acid). On saturating this acid with hydrogen, stearic acid melting at 68° was obtained.

Parnas also found indications of the presence of very small amounts of oleic acid, and of an acid with three unsaturated double bonds, but it was considered that these might well be derived from impurities

in the kephalin, and Parnas finally concluded that the chief unsaturated fatty acid present in kephalin was kephalin linolic acid.

It seemed, therefore, to be quite definitely established that only one unsaturated fatty acid occurred in kephalin, and that this acid had been satisfactorily identified as a linolic acid.

The results of more recent work on the kephalin fatty acids do not support this conclusion, and the presence of linolic acid in kephalin needs further confirmation. MacArthur and Burton [1916] first found that oleic acid constituted about 50 per cent. of the total fatty acids of kephalin. They found also indications of the presence of other acids which they suggested might be (1) kephalinic acid containing three double bonds, and (2) clupanodonic acid in which four double bonds are present; both these acids contain eighteen carbon atoms. These authors also suggested that possibly the unsaturated acid present might be identical with the arachidonic acid isolated by Hartley from pig's liver.

Finally, Levene and Rolf [1922, 1], working with kephalin entirely free from lecithin and from neutral fats, isolated from it oleic and arachidonic acids; the former was identified by its iodine number, and by the analysis and melting-point of the stearic acid obtained from it on reduction, the latter by its reduction to arachidic acid and by the analysis of its octobromide. They obtained evidence of the presence of other unsaturated acids, but were unable to identify them with certainty. It seems most probable, therefore, that the acids present in kephalin are oleic and arachidonic, together with other unsaturated acids, possibly linolic. But whereas both palmitic and stearic acids are obtained from lecithin, stearic alone of the saturated acids has been identified in kephalin.

The Glycerophosphoric Acid of Kephalin.

The presence of glycerol in kephalin has been accepted by all observers, though its identification has apparently been arrived at in an indirect manner. Thudichum claims to have isolated glycerophosphoric acid from kephalin, but as his kephalin was obviously impure, as indicated by the presence of considerable amounts of choline, no great reliance can be placed on this result. The same observation applies to Cousin's statement [1907] that the glycerophosphoric acid in kephalin is identical with that of lecithin. The results of Fränkel and Dimitz [1909], who worked with a purified choline-free

specimen of kephalin, support the view that glycerophosphoric acid is present. These observers obtained from kephalin a barium salt, which had the general properties of barium glycerophosphate, and contained practically the theoretical amount of barium. The composition of this salt was given as $C_3H_7O_6PBa + H_2O$, though the only analytical figures furnished refer to the barium content. Since the barium salt was optically active they ascribed to the corresponding acid the asymmetrical formula—

$$\begin{array}{l} CH_2 \cdot OH \\ | \\ CH \cdot OH \\ | \\ CH_2 \cdot O \cdot PO_3H_2 \end{array}$$

just as Willstätter and Lüdecke [1904] did for the corresponding lecithin compound. This barium compound was found to be *dextro*-rotatory, and contained *one* molecule of water of crystallisation. It differed, therefore, from the corresponding lecithin salt isolated by Willstätter and Lüdecke, which was *lævo*-rotatory, and contained only *one-half* molecule of water. Unlike the glycerophosphoric acid of lecithin, it was very resistant to acid hydrolysis.

Levene and West [1918, 1] reduced both lecithin and kephalin, and found that the optical rotations of both dihydrolecithin and dihydrokephalin were identical. They concluded that both substances contained the same form of glycerophosphoric acid. Levene and Rolf [1919] then repeated the work of Willstätter and Lüdecke on lecithin, and applied the same method of investigation to the glycerophosphoric acid of kephalin. From both lipins, specimens of the barium salt of glycerophosphoric acid were prepared, and were found to give the same optical rotation, and to be similar in their properties.

Ba salt of lecithin glycerophosphoric acid $[\alpha]_D^{20} = -0{\cdot}74$.
Ba salt of kephalin glycerophosphoric acid $[\alpha]_D^{20} = -0{\cdot}69$.

The authors, however, state that the impure barium glycerophosphate first isolated from the hydrolytic products of kephalin was dextro-rotatory, whereas the barium glycerophosphate isolated from lecithin never showed dextro-rotation. Apparently decomposition products are formed by the hydrolysis of kephalin which are dextro-rotatory, and which are present as impurities in the crude barium glycerophosphate. This apparently accounts for the results obtained by Fränkel and Dimitz.

The work of Levene and his colleagues seems to have definitely settled the question of the nature of the glycerophosphoric acid of

kephalin; there can be little doubt that it is identical with that prepared from lecithin.

The Composition and Elementary Analysis of Kephalin.

According to the above observations, kephalin is split up by hydrolysis, giving—

(1) A base, aminoethyl alcohol $NH_2CH_2 . CH_2 . OH$.
(2) Glycerophosphoric acid.
(3) A saturated fatty acid, stearic $C_{18}H_{36}O_2$. Two unsaturated fatty acids; arachidonic $C_{20}H_{32}O_2$ and oleic acid $C_{18}H_{34}O_2$.

Assuming that as in lecithin one saturated and one unsaturated fatty acid radicle are present in the kephalin molecule in equimolecular proportions, and that glycerol and phosphorus are combined as glycerophosphoric acid, we should have the following formulæ for kephalin according as arachidonic or oleic was the unsaturated acid present in the molecule :—

With arachidonic, $C_{42}H_{78}NPO_8$	C = 67·27 per cent.	With oleic, $C_{41}H_{80}NPO_8$	C = 66·04 per cent.
	H = 10·17 ,, ,,		H = 10·74 ,, ,,
	N = 1·82 ,, ,,		N = 1·88 ,, ,,
	P = 4·04 ,, ,,		P = 4·13 ,, ,,
	N : P ratio = 1 : 1		

A comparison of the theoretical value with those actually obtained by various observers shows that a considerable discrepancy exists, particularly with regard to the percentage of C and H. In such a large molecule as that of kephalin no great weight can be attached to small differences in these figures; but here, even in cases of very carefully purified kephalin, the difference is greater than can reasonably be accounted for by experimental error.

The chief results obtained by various investigators are seen in the table on the opposite page.

From these figures it appears that the percentage of carbon actually found is almost always 5 per cent. less or more than the theoretical requirements, while the other atoms also are generally too low. In fact, as pointed out by Levene and West [1916], the formula $C_{41}H_{78}NPO_{13}$ agrees much better with the analytical figures found than does the calculated $C_{41}H_{78}NPO_8$. Thudichum realised this difficulty, and endeavoured to account for the difference by assuming that each molecule of kephalin contained 5 molecules of H_2O. His kephalin gave analytical figures corresponding to the formula $C_{42}H_{79}NPO_{13}$, which on deduction of 5 molecules of $H_2O = C_{42}H_{69}NPO_8$. This

Investigator.	Source of Kephalin.	C.	H.	N.	P.	N : P Ratio.
Thudichum [1884]	Brain (human and ox)	60·00	9·38	1·68	4·27	1 : 0·87
Zuelzer [1899]	,, (ox)	60·20	9·80	3·80	2·60	1 : 0·32
Koch [1902]	,, (sheep)	59·50	9·80	1·75	3·85	1 : 1·01
Cousin [1906]	,,	—	—	1·82	3·89	1 : 1·04
Stern and Thierfelder [1907]	Egg-yolk	59·68	9·74	1·57	3·64	1 : 0·96
Stern and Thierfelder [1907]	,, ,,	65·66	11·54	1·37	3·96	1 : 0·77
Falk [1908]	Nerves	55·75	9·66	1·94	4·42	1 : 0·97
,, ,,	Brain (human)	57·56	9·21	2·93	3·23	—
Fränkel and Neubauer [1909]	,, ,,	61·99 62·12	9·85 9·87	1·65 1·69	3·44 3·45	1 : 1·06 1 : 1·08
Parnas [1909]	,, ,,	—	—	1·83	3·86	1 : 1·05
Frank [1913]	Liver	57·10	9·62	1·72	3·91	1 : 0·97
Baumann [1913]	Brain (human)	—	—	1·84	—	—
Renall [1913]	,, (ox)	—	—	1·69	3·56	1 : 1·05
,, ,,	,, (sheep)	—	—	1·92	4·27	1 : 1·00
Bürger and Beumer [1913]	Erythrocytes	—	—	1·78	4·06	1 : 0·97
Levene and West (1916)	Brain	60·00	9·62	1·78	3·60	1 : 1·09
,, ,, [1916, 2]	Liver	60·33	9·01	1·86	3·75	1 : 1·10
,, ,, ,,	Kidney	60·17	8·95	1·70	3·65	1 : 1·03
,, ,, ,,	Egg-yolk	60·00	9·62	1·78	3·69	1 : 1·07

latter formula agrees well with the theoretical one, except that the hydrogen content is much too low. Thudichum realised that the assumption that kephalin took up 5 atoms of oxygen would give analytical numbers agreeing with those actually found, but he rejected this explanation on theoretical grounds.

The apparent excess of oxygen as ascertained by analysis may be to some extent accounted for by oxidation of the unsaturated acid present in the kephalin. It appears probable that every sample of kephalin hitherto analysed had undergone oxidation to a greater or less extent during the process of preparation.

An iodine value carried out immediately before elementary analysis would furnish some evidence of the amount of oxidation which had taken place in the molecule. That certain samples of kephalin had the greater part of their unsaturated acid oxidised before analysis was carried out is obvious from the description of the methods used in their preparation. On the other hand, the analyses indicate a high proportion of oxygen in many samples of kephalin where precautions against oxidation had apparently been adopted. If, as Levene has shown, the acids present are indeed the same as occur in true lecithin, there must be some other cause to account for the discrepancy between the calculated and observed numbers for kephalin since the calculated and observed numbers for the composition of lecithin show very much better agreement.

Levene and West [1916] endeavoured to estimate the percentage of the different components of kephalin present in the molecule, and obtained the following results :—

	Found.	Calculated for $C_{41}H_{78}NPO_8$.
Base	8·26	8·2
Glycerol	10·00	12·4
Phosphoric acid	12·17	13·2
Fatty acids	63·40	75·9
Totals . . .	93·83	109·7

There is a marked deficiency in the amount of fatty acids obtained which might be accounted for in two ways: either the whole of the fatty acids were not split off by the method of hydrolysis employed, or some of the fatty acid radicle had already been split off from the kephalin before the analysis was made, during the course of preparation of the original specimen. In obtaining the acids the kephalin was boiled with 3 per cent. H_2SO_4 for twenty-four hours, but since kephalin is very resistant to hydrolysis, and specimens hydrolysed for twenty-four to thirty-five hours with 5 per cent. hydrochloric acid "still seemed to contain unchanged kephalin" [Fränkel and Dimitz, 1909], it is just possible that the whole of the acids were not split off under the conditions of the experiment, though this does not appear very probable.

Levene and West [1916] attempted to purify kephalin by hydrogenating a carefully purified specimen, but the result was not very successful, the kephalin having apparently already undergone change. They succeeded, however, in preparing a specimen of dihydrolecithin from a crude lecithin which contained 20 per cent. of its nitrogen in the form of amino-nitrogen. From this substance, by a process of fractional crystallisation, a sample of reduced kephalin containing 98·33 per cent. of its nitrogen in the amino-form was obtained :—

	C Per Cent.	H Per Cent.	N Per Cent.	P Per Cent.	Percentage of Total Nitrogen in Amino-form.
Theory for reduced kephalin containing 2 stearyl radicles	65·80	11·05	1·87	4·15	100·0
Found	65·33	10·50	1·94	3·87	98·33

It was thus shown that it is possible to obtain a reduced kephalin which gives analytical numbers agreeing with those required by

theory. An explanation for the low analytical results given by the unreduced kephalin was now forthcoming. In the first edition of this work a substance " cuorin " was described among the individual lipins, having a " N : P " ratio 1 : 2 ; it was there pointed out that from the nature of its preparation this was possibly to be regarded as a mixture of decomposition products of kephalin. Levene and Komatsu [1919, 1] have since confirmed this ; they found that by using identical methods of preparation, products were obtained varying in composition from cuorin to kephalin, and that from cuorin itself kephalin could be isolated. Finally, they showed that various hydrolytic decomposition products of kephalin could be identified, amongst them monostearyl glycerophosphoric acid (i.e. kephalin minus its base and minus one fatty acid radicle) and monostearyl glycerophosphoric acid aminoethanol ester (i.e. kephalin minus the unsaturated fatty acid radicle). The percentage composition of these products is shown in the following table :—

	C Per Cent.	H Per Cent.	N Per Cent.	P Per Cent.
Monostearyl glycerophosphoric acid aminoethanol ester	57·3	9·9	2·7	6·4
Monostearyl glycerophosphoric acid . .	55·7	9·57	0·0	6·85
Kephalin (theoretical)	66·16	10·57	1·88	4·18
,, (found)	60·13	9·50	1·80	3·70

It is clear that the presence of such decomposition products as impurities in the kephalin would lower both the percentage of carbon and of hydrogen.

The most satisfactory explanation of the discrepancies between the numbers found on analysis of kephalin and those required by theory seems to be that kephalin as usually prepared is not a single individual but a mixture of kephalin with its hydrolytic degradation products. Oxidation of the unsaturated acid radicle in the molecule probably plays some part in the changes that occur, but the extreme tendency of the kephalin molecule to undergo hydrolysis and to split off decomposition products seems to be the most prominent factor in preventing the preparation of a pure kephalin.

If it be indeed certain that kephalin and lecithin both contain the same glycerophosphoric acid and fatty acid radicles, then the difference in the properties of these two substances must be due to the different nature of their respective basic radicles.

It has, for instance, been noted particularly by Parnas and by

Thudichum that when kephalin is hydrolysed it is exceedingly difficult to get phosphorus-free fatty acids; in fact, definite intermediate compounds containing fatty acids and phosphorus have been obtained. Thudichum's substance kephalo-phosphoric acid, has been already referred to. The product obtained by Parnas was a tetrabasic body corresponding to the formula $C_{27}H_{53}O_{10}PBa_2$. This product was isolated after the kephalin had been autoclaved for twelve hours at 120° with barium hydrate; on further hydrolysis with sodium hydroxide, Parnas found that this substance contained a considerable amount of linòlic acid, but apparently no stearic acid. If this compound can be accepted as a chemical unit it would appear that the unsaturated acid of kephalin must be in intimate relationship with the phosphorus group, while the stearic acid is split off with comparative ease. Levene and Komatsu have obtained a hydrolytic decomposition product of kephalin which contained all the groups originally present except the *unsaturated* fatty acid radicle. In lecithin, on the other hand, both acids are easily separated by hydrolysis. Again, from kephalin Levene and Rolf [1919] have not only isolated the decomposition products already described, but have also brought forward evidence of the existence of dextro-rotatory nitrogenous decomposition products of kephalin. Choline, the basic constituent of lecithin, is a much stronger base than aminoethyl alcohol, the basic constituent of kephalin, and this difference in the properties of their respective bases no doubt exerts a considerable influence on the tendency of these lipins to form decomposition products.

The question as to whether the difference in the nature of the basic components of kephalin and lecithin is alone sufficient to account for the greater tendency of the kephalin structure to form decomposition products cannot yet be regarded as definitely settled.

On the whole, the recent work of Levene and his colleagues seems to have turned the balance of evidence in favour of the view that the kephalin and lecithin molecules are built up on the same plan. Further research may confirm the interesting work of MacArthur, and it may be that both aminoethyl alcohol and an aminoacid may act as the basic constituents of different kephalins.

Since three fatty acid radicles have now been shown to be derived from kephalin, and since from the structure assigned to it there is only place for two such radicles in the kephalin molecule, we must assume that various kephalins exist differing in the nature of their fatty acids.

CHIEF PROPERTIES OF KEPHALIN.

The chief properties of kephalin have been described by Thudichum [1884], Falk [1908] and Parnas [1909], but since it is quite clear that none of these observers were dealing with pure kephalin, the description of its properties must be accepted with reserve; a pure specimen of kephalin has probably never yet been prepared.

Kephalin as usually obtained is a hard yellowish-brown somewhat brittle substance, which can be easily pulverised; it is very hygroscopic and in the presence of moisture forms a sticky tenacious mass. The colour of kephalin is due to impurities, and Parnas isolated a specimen which was colourless. Kephalin has not been obtained in crystalline form. From very cold ether solution it separates in the form of doubly-refracting globules, which show no definite structure (Parnas).

According to Thudichum, kephalin "when not too much hydrated" is highly soluble in ether, and when dry is soluble in anhydrous ether in almost any proportions. This statement of Thudichum appears to be incorrect, for Parnas found that kephalin is insoluble in *anhydrous* ether, but dissolves readily in ether containing 1 per cent. of water, an observation which has been corroborated by Levene and West [1916]. Kephalin dissolves also in chloroform, benzene, petroleum ether and carbon disulphide: in cold acetic ether it is practically insoluble, but dissolves on heating and falls out on cooling: like other phospholipins, it is insoluble in acetone.

With regard to the behaviour of kephalin towards alcohol, various contradictory statements have been made. Thudichum's kephalin was slightly soluble in cold alcohol and fairly soluble in hot alcohol, while Koch's preparation was quite insoluble in alcohol, though the presence of a small amount of hydrochloric acid rendered it fairly soluble. There seems no doubt that kephalin is to some extent soluble in alcohol, but the degree of solubility may depend on the treatment adopted in its isolation. Thus Fränkel and Neubauer found that kephalin prepared by alcohol precipitation was quite insoluble in this reagent, but that the same sample of kephalin when purified by means of hydrochloric acid was easily soluble: on treatment with acetone it again became insoluble.

Since kephalin usually contains bases such as calcium and potassium an explanation of this action of hydrochloric acid was sought in the supposition that ordinary alcohol-insoluble kephalin was really a compound from which free kephalin was liberated on treatment with acid.

In this connexion Bang [1911] suggests the probability that free kephalin is really alcohol soluble, but this seems to be discounted by the action of acetone on the soluble kephalin.

With water, kephalin forms suspensions and ultimately clear colloidal solutions. From its aqueous solution kephalin is precipitated by treatment with hydrochloric acid and with various inorganic and organic acids. Tartaric acid does not produce this effect. This separation does not depend on the formation of compounds of kephalin with acids as Thudichum suggested, but is apparently a physical reaction in which the negatively charged kephalin is precipitated by the positively charged acid [Fränkel and Neubauer, 1909]. Kephalin may also be obtained from colloidal solutions by centrifuging [Parnas, 1909].

Kephalin is very hygroscopic, and has such a marked affinity for water that the expulsion of the last trace of moisture is obtained only after long treatment *in vacuo* (Thudichum).

By the action of water, acids or alkalies, kephalin is partly decomposed, the base and part of the fatty acids being split off with great ease; on the other hand, complete hydrolysis of kephalin is not easily accomplished, even on boiling with acids or alkalies for considerable periods. On exposure to air it readily absorbs oxygen, a property dependent on the unsaturated fatty acid of the molecule. Solutions of kephalin in ether are generally characterised by a marked fluorescence, which, according to Parnas, depends on the interaction of salts with the earlier decomposition products of kephalin. When an ethereal solution of kephalin is shaken with hydrochloric acid, the fluorescence disappears, but returns on the addition of a small amount of lime water to the washed ethereal solution.

According to Parnas [1909] and Falk [1908] the melting-point of kephalin is 174°. Fränkel's specimen melted at 175°.

Kephalin always contains inorganic constituents such as calcium, potassium and ammonium: Parnas found traces of magnesium as well, but could not confirm the statement of Falk that iron and copper were also present.

According to Fränkel and Neubauer, kephalin is optically active and rotates the plane of polarised light to the left. In one experiment 0·11 gm. of kephalin dissolved in 10 c.c. petroleum ether and examined in a tube 1 decimetre long gave a rotation of 0·15° to the right; for this concentration the result indicates a specific rotation of + 13·6°.

Compounds of Kephalin.

Kephalin forms compounds with cadmium chloride and platinum chloride, but these combinations are not well characterised. For the cadmium chloride compound Thudichum obtained on analysis 89·38 per cent. kephalin and 10·62 per cent. cadmium chloride, while theory requires 17·97 per cent. cadmium chloride. For the platinum chloride combination the same observer found 3·6 per cent. platinum chloride against the theoretical 9·5 per cent. Both these combinations are soluble in ether but insoluble in alcohol. From its aqueous colloidal solution kephalin is precipitated by many salts, alkalies and other reagents [Thudichum, 1884; Koch, 1903, 1907], but many of these precipitates are not true kephalin compounds, but result from the physical action of these substances on the colloidal kephalin solution. Kephalin appears to form a definite compound with lead acetate in the presence of ammonia, a reaction which is often used in its isolation and purification.

The subject of kephalin combinations is in an unsatisfactory condition and requires further investigation. Levene and West [1916, 3] describe phenyl- and naphthyl-ureido derivatives of kephalin.

Some Kephalin-like Substances (Thudichum).

Besides ordinary kephalin, Thudichum [1884] described certain other allied substances which he claimed to have isolated from brain. These bodies show a marked similarity with kephalin, both in elementary composition and general properties. From our knowledge of kephalin it is almost certain that Thudichum's substances were oxidised kephalins, which in many or all cases contained impurities as well.

Thudichum mentions :—

Amidokephalin	$C_{126}H_{239}N_5P_3O_{39}$.
Oxikephalin (as $CdCl_2$ compound)	$C_{42}H_{79}NPO_{14} . CdCl_2$.
Peroxikephalin	$C_{42}H_{79}NPO_{15}$.
Kephaloidin	Same as kephalin (but different properties).
Oxikephaloidin (as $CdCl_2$ compound)	$2(C_{42}H_{75}NPO_{14})CdCl_2$.

Many of these substances were prepared from specimens of crude kephalin, which had not undergone the ordinary processes of purification used by Thudichum in preparing kephalin.

DERIVATIVES OF KEPHALIN.

(*a*) *Lysokephalin.*

Lysokephalin [Levene, Rolf and Simms, 1924] is prepared mixed with lysolecithin when crude lecithin is treated with cobra venom; its separation from lysolecithin has already been described (see p. 38).

It is a gleaming white powder, crystallising from chloroform in transparent needles. It is less soluble than the corresponding lysolecithin. It may be dissolved in hot absolute methyl alcohol, from which it precipitates crystalline on the addition of water. With water it forms an emulsion which dissolves immediately on the addition of caustic soda. After recrystallisation from pyridine it melted sharply at 212° to 213°. Its specific rotation was determined in glacial acetic solution, and was found to be $[\alpha]_D = + 2{\cdot}0$. It has two dissociation constants $K_1 = 3 \times 10^{-4}$ and $K_2 = 3{\cdot}4 \times 10^{-10}$, and the isoelectric range is from pH 5·5 to 7·5.

The only fatty acid isolated from the hydrolytic products of lysokephalin was stearic acid.

(*b*) *Dihydrokephalin.*

A sample of crude reduced lecithin was prepared as described on page 39. This was recrystallised from a mixture of equal parts of chloroform and ethyl-methyl ketone many times, and finally from a mixture of ethyl alcohol and chloroform. Dihydrokephalin [Levene and West, 1918] was thus separated; it is less soluble in all organic solvents than the corresponding dihydrolecithin. Its specific rotation was $[\alpha]_D = + 6{\cdot}0$.

SPHINGOMYELIN.

When brain tissue is extracted with warm alcohol and the alcohol extract concentrated and cooled, a white powdery substance separates in the form of a precipitate. This precipitate is composed largely of sphingomyelin and cerebrosides. Sphingomyelin, which was first isolated by Thudichum [1884], differs from the phosphatides already described in being a white crystalline stable substance. It is very abundant in the brain, but occurs to some extent in many other tissues, and is always found in association with cerebrosides, with which it has many properties in common; on this account its separation in pure form is exceedingly difficult and nearly all the sphingomyelins described have been contaminated with cerebrosides to a greater or less degree. These mixtures of sphingomyelin and cerebrosides (often referred to as "*Protagon*") have hitherto given rise to much confusion, but modern work has practically removed the difficulties. This aspect of the subject is fully discussed in the section on protagon.

Thudichum recognised that sphingomyelin was a diaminomonophosphatide (N : P = 2 : 1); he showed that it differed from other phosphatides in containing no glycerol.

As the result of hydrolysis of various specimens of impure sphingomyelin with barium hydroxide, Thudichum described the following products:—

(1) Phosphoric acid.
(2) A barium salt soluble in ether.
(3) A fatty acid.
(4) An alcohol—sphingol.
(5) Two bases—sphingosine and neurine (choline, see footnote, p. 40).

The work of later observers has confirmed the existence of all these products with the exception of the alcohol, sphingol. This substance, according to Thudichum, corresponded to the formula $C_9H_{18}O$ or $C_{18}H_{36}O_2$. Assuming the latter formula to be the correct one, the body would constitute an isomer of stearic acid. Rosenheim and Tebb [1909, 1] introduced a new method for the purification of sphingomyelin, and from the product thus purified isolated an intermediate hydrolytic product from which on complete hydrolysis a crystalline alcohol was isolated; the composition of this was not determined. Levene, working more recently with the purest material available, has not, however, obtained evidence of the existence of such an alcohol,

and he infers from the proportion of other hydrolytic products which were separated, that there is no room for this alcohol in the sphingomyelin molecule. We must, therefore, consider it as doubtful whether Thudichum's sphingol exists.

Hydrolytic Products of Sphingomyelin.

(*a*) *The Bases.*

The existence of the two bases, choline and sphingosine, has been confirmed by the work of all subsequent investigators.

Sphingosine.

Sphingosine was first isolated by Thudichum, who, from analyses of its salts, correctly ascribed to it the formula $C_{17}H_{35}NO_2$. From its behaviour towards acids and bases Thudichum considered the possibility of the substance having the structure of an amino acid, and observed that it might possibly be regarded as an acid of the $C_nH_{2n}O_2$ series, in which one atom of hydrogen was replaced by an amino group. The composition of such a substance would be expressed by the formula $C_{17}H_{33}(NH_2)O_2$. On the other hand, since the body had great affinity for acids and was precipitated by most of the specific reagents for alkaloids, Thudichum considered that, on the whole, the evidence pointed to the conclusion that sphingosine was an alkaloidal base.

Sphingosine was next found by Thierfelder [1904], who in conjunction with his pupils independently established the formula $C_{17}H_{35}NO_2$ for this substance. This formula agreed with Thudichum's, but it is interesting to note that Thierfelder's early investigations were carried out in ignorance of Thudichum's work. Thierfelder also showed that sphingosine was a monacidic base yielding stable salts with mineral acids [Thierfelder, 1904, 1905; Kitagawa and Thierfelder, 1906].

After 1906 no important contribution to the chemistry of sphingosine appeared until the end of 1911, when Levene and Jacobs [1911, 1912] showed that sphingosine was a dihydroxy derivative of a primary unsaturated amine. About the same time Riesser and Thierfelder [1912] and Thomas and Thierfelder [1912] furnished independent evidence to the same effect. The principal reactions of sphingosine on which these statements were based are as follows [Levene and Jacobs, 1912]:—

1. Sphingosine gives up the whole of its nitrogen on treatment with nitrous acid by Van Slyke's method. The nitrogen must therefore have been present as a primary NH_2 group.
2. Sphingosine readily absorbs hydrogen on treatment by the method of Paal and forms a di-hydrosphingosine, thus indicating the presence of a double bond:—

$$\underset{\text{Sphingosine.}}{C_{17}H_{35}NO_2} + H_2 = \underset{\text{Dihydrosphingosine.}}{C_{17}H_{37}NO_2}$$

3. On acetylation a *tri*acetyl derivative is formed which no longer contains the primary amino group. The amino group has therefore been responsible for one acetyl group; the other two indicate the presence of two (OH) groups.

So far it was proved that sphingosine contained two (OH) groups, one primary (NH_2) group and a double bond, but nothing was known with regard to their position in the molecule. There was also no knowledge as to whether the carbon atoms were linked together in a normal or branched chain.

On treatment of sphingosine with oxidising agents, oxidation should take place at the double bond or possibly a carbon atom attached to an amino or hydroxyl group might be oxidised. On careful oxidation with chromium trioxide, Lapworth [1913] obtained a normal 13-carbon or tridecylic acid, and for this reason he concluded that the carbon atoms of sphingosine were linked together in a straight chain. This observation of Lapworth limited the position of the amino and hydroxyl groups to the four terminal carbons of the chain and rendered it highly probable that the double bond existed between the thirteenth and fourteenth carbon atoms:—

$$CH_3(CH_2)_{11} . CH = CH . C_3H_4(OH)_2(NH_2).$$

Lapworth's results were confirmed and extended by Levene and West [1914; 1914, 2], who saturated sphingosine with hydrogen by Paal's method and oxidised the dihydrosphingosine formed. In this case cleavage took place not between the thirteenth and fourteenth carbon atoms, but between the fifteenth and sixteenth, with the formation of a 15-carbon acid which was identified as normal pentadecylic acid.

The cleavage of sphingosine described by Lapworth must therefore have taken place at the double bond since saturation of the unsaturated linkage prevented oxidation at this point. The formation of pentadecylic acid also further limited the position of the (OH)

and (NH_2) groups to the three terminal carbon atoms. The formula of sphingosine may therefore be expressed approximately as follows :—

$$\underbrace{CH_3 . (CH_2)_{11}CH}_{\text{Tridecylic acid on oxidation.}} = CH . CH(OH) . \underbrace{CH(OH) . CH_2(NH_2)}_{\text{Pentadecylic acid on oxidation of saturated base.}}$$

Attempts to determine the distribution of the amino and hydroxy groups on the last three carbon atoms have been made by Levene and Jacobs [1912], who endeavoured to reduce dihydrosphingosine to the corresponding amine. The normal heptyldecamine having the composition $CH_3 . (CH_2)_{16} . NH_2$ has been obtained synthetically, and comparison of the two bodies should determine whether or not they are similar. If they were found to be identical the composition of sphingosine would be settled, but so far attempts to reduce dihydrosphingosine to the corresponding amine have proved unsuccessful, an unsaturated amine being obtained.

The synthesis of 1-amino 2-hydroxy *n*-heptadecane has recently been carried out by Levene and Haller [1925].

A description of various salts and derivatives of sphingosine is given by Levene and West [1916, 1].

(*b*) *The Fatty Acids of Sphingomyelin.*

Thudichum's ether-soluble barium salt might probably have been the salt of a fatty acid, but no data were furnished with regard to its composition. Thudichum obtained, however, a free fatty acid whose barium and lead salts were insoluble in ether and in alcohol. This acid corresponded to the formula $C_{18}H_{36}O_2$. While agreeing with stearic acid in its elementary analysis, it melted at 57°, thus differing from stearic acid, which melts at 69°. Thudichum considered this acid to be an isomer of stearic acid, and on this account he named it sphingostearic acid.

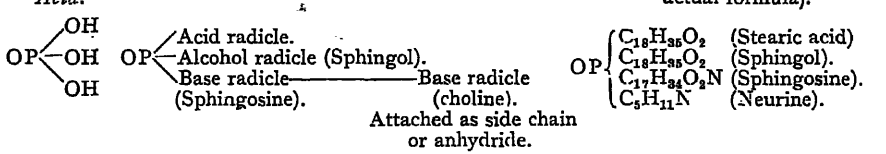
Levene [1913] heated sphingomyelin with alcohol containing 7 per cent. of sulphuric acid for six hours, and showed that one of the hydrolytic products was an acid which melted at 81°. This acid was identified as lignoceric acid, $C_{24}H_{48}O_2$ (see p. 101, also Leathes and Raper, 1925). Subsequently the method of purifying sphingomyelin was improved, and working with a pure specimen Levene isolated two acids : (1) lignoceric acid, $C_{24}H_{48}O_2$; and (2) a hydroxy-acid of low melting-point which could not be obtained pure ; the latter constituted at least 50 per cent. of the fatty acids of sphingomyelin.

(c) *Phosphoric Acid of Sphingomyelin.*

This was always obtained free and never in combination with glycerol, as in the case of lecithin and other phospholipins. Thudichum therefore came to the conclusion that sphingomyelin contained no glycerol, an observation which is now accepted by all observers.

Composition and Structure of Sphingomyelin.

Since free phosphoric acid was always obtained on hydrolysis and glycerophosphoric acid was absent, Thudichum suggested that the composition of sphingomyelin might be represented by a formula in which the three (OH) groups of phosphoric acid were substituted by an acid, alcohol and basic radicle, the other base being attached as a side chain, or anhydride, to a radicle already substituted:—



In the main, Thudichum's general observations on sphingomyelin have been confirmed by subsequent research, though in several points he was obviously in error.

Sphingomyelin was investigated by Rosenheim and Tebb [1908; 1909, 1; 1910, 1], who, using a new method, isolated what they considered to be a fairly pure specimen. The general properties of this substance agreed with those given by Thudichum, and on hydrolysis it yielded choline and fatty acids, but no glycerine. On partial hydrolysis a body was isolated which had some resemblance to the simplest nucleic acids; on complete hydrolysis this intermediate product yielded phosphoric acid, a base and a crystalline alcohol. With regard to the structural composition of sphingomyelin, Rosenheim and Tebb expressed no opinion.

All the specimens of sphingomyelin investigated up to this point were impure and contained cerebrosides, but Levene [1914] reported a method for obtaining pure sphingomyelin and ascertained the best conditions for the hydrolysis of this substance. Working with pure specimens, Levene [1916] obtained the following products on hydrolysis:—

1. Phosphoric acid.
2. Two fatty acids: (*a*) lignoceric acid, $C_{24}H_{48}O_2$; (*b*) a hydroxy-acid of low melting-point.
3. Two bases: (*a*) choline, $C_5H_{15}NO_2$; (*b*) sphingosine, $C_{17}H_{35}NO_2$.

Another base corresponding to the constitution $C_{17}H_{33}NO$ (sphingosine minus H_2O) was found, but evidence was obtained that this base was a secondary product formed from sphingosine.

When sphingomyelin is hydrolysed with alcohol and water, sphingosine loses a molecule of water, giving rise to a base of the nature of anhydrosphingosine. This secondary product must contain two unsaturated linkages, one of them being in the position of the double bond in sphingosine. The relation of this body to sphingosine will be at once apparent on reference to the structural formula of the latter substance. The (OH) and (H) of sphingosine shown in heavy type are supposed to be eliminated as water. The position of the second double bond in the resulting substance is arbitrary :—

Sphingosine

$$CH_3 . (CH_2)_{11}CH = CH . CH(\mathbf{OH}) . CH(OH) . CH_2(NH_2).$$

Anhydrosphingosine

$$CH_3 . (CH_2)_{11}CH = CH . CH = C(OH) . CH_2(NH_2).$$

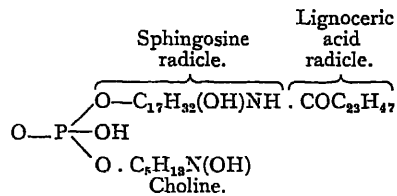
On reduction of this secondary base with hydrogen the resulting product possessed the structure of hydroxyheptadecylamine, $C_{17}H_{34}(OH)NH_2$, and for this reduced base Levene proposed the name sphingine. Levene also made the important observation that the sphingosine was probably in combination with lignoceric acid in the sphingomyelin molecule, for he succeeded in isolating an intermediate product of hydrolysis which, after saturation with hydrogen in the presence of palladium, had the elementary composition of lignoceryl sphingine. This substance did not form salts with mineral acids; it gave no nitrogen on treatment with nitrous acid, and therefore did not contain an (NH_2) group. It was probable therefore that the junction of lignoceric acid with sphingine took place through the (NH_2) group, so that the compound might be represented by the formula

$$\underset{\text{Sphingine radicle.}}{C_{17}H_{34}(OH)NH}—\underset{\text{Lignoceric acid radicle.}}{CO . C_{23}H_{47}}$$

Only a small amount of this intermediate compound was obtained, and no further investigations were carried out on account of lack of material.

Since Levene's sphingomyelin yielded 34 per cent. of its weight in

the form of sphingosine and 43 per cent. in the form of organic acids, and since the substance contained choline and phosphoric acid as well, it is obvious that there is no room in the molecule for the alcohol sphingol which Thudichum claimed to be present. Levene therefore believes that sphingomyelin does not contain sphingol. He suggests the structural expression for sphingomyelin :—



It will be seen that this formula, though differing in detail from that suggested by Thudichum, is based on the same general principle ; it allows only for one acid, and Levene explains the presence of the second acid, which he isolated on hydrolysis of sphingomyelin, by the assumption that the lignoceric acid may be substituted by this other acid. In this case sphingomyelin must be regarded as a mixture of two phospholipins differing only in their fatty acids. On the other hand, these two substances might be combined, constituting a diphosphatide. There is at present no evidence to decide which of these views is correct.

Elementary Analysis of Sphingomyelin.

Pure sphingomyelin was only obtained in 1916 [Levene, 1916], and all samples investigated before this time were contaminated with galactolipins. The purest samples isolated before Levene succeeded in obtaining a pure specimen were described by Rosenheim and Tebb [1908, 1910, 1], but even these products contained some galactolipin. At present we have data for only four specimens of pure sphingomyelin, all isolated by Levene. The results of analysis of these substances are indicated in the following table, which also shows the percentage of sphingosine and acids obtained from sphingomyelin :—

Source.	C.	H.	N.	P.	Sphingosine, Per Cent.	Fatty Acids, Per Cent.	Ratio N : P.
Brain . .	66·59	11·26	3·78	3·99	34·10	43·00	2·09 : 1
Kidney . .	64·80	11·41	3·50	3·82	32·10	49·00	2·03 : 1
Liver . .	64·47	11·57	3·41	3·81	32·14	41·70	1·98 : 1
Egg-yolk .	65·56	11 68	3·84	4·22	33·70	43·40	2·01 : 1

From the general agreement of these figures Levene conjectured that the sphingomyelins of brain, kidney, liver, and egg-yolk were identical. If sphingomyelin is a mixture of two phospholipins the slight difference in composition of the various specimens may be accounted for on the supposition that the proportion of the two substances varies somewhat in the material obtained from different organs.

Sphingomyelin-like Bodies.

Various substances having the properties of sphingomyelin have from time to time been isolated by different authors in the course of their work on phospholipins. Thus Stern and Thierfelder [1907] described a substance which they isolated from egg-yolk and referred to as "Weisse Substanz." Thierfelder recognised that this body belonged to the sphingomyelin group of Thudichum. A similar substance was described by MacLean [1912, 2], who isolated it from horse kidneys. "Carnaubon," found in ox kidneys by Dunham and Jacobson [1910], and a corresponding substance isolated by MacLean [1913] from heart muscle, all come under this group; also the apomyelin and amidomyelin of Thudichum, and the diaminomonophosphatide obtained by Fränkel and Offer [1910] from horse pancreas. All these substances proved to be diaminophosphatides (N : P = 2 : 1), but differed materially in elementary composition, and nearly all were found to yield a reducing sugar on hydrolysis. This reduction was due to the galactose present in the contaminating cerebroside, and we now know from the work of Rosenheim and of Levene that all these bodies were mixtures of sphingomyelin with cerebrosides. The extraordinary difficulty experienced in obtaining pure sphingomyelin is discussed later.

Comparison of the analytical figures obtained from these bodies with the figures obtained by Levene for pure specimens of sphingomyelin indicates that many of them must have contained considerable amounts of cerebrosides. See table on opposite page.

It is a remarkable coincidence that mixtures of substances should give such close figures, as shown in the table, in certain cases. Even the determination of the so-called melting-point is not of much value in identifying these bodies, as the similarity of certain of their "melting-points," or, more correctly, their clearing-points (see p. 107), might suggest that they were definite chemical entities. Thus the substance from kidney "melted" at 182° to 183°, and the heart substance at

Observer.	Source of Material.	C.	H.	N.	P.	Ratio N : P.	Name Given to Substance by Investigator.
Rosenheim and Tebb [1908] . .	Brain .	62·90	11·54	3·3	3·46	2·11 : 1	Sphingomyelin.
Stern and Thierfelder [1907] . . .	Egg-yolk .	68·15	12·14	2·77	3·22	1·9 : 1	"Weisse Substanz."
Dunham and Jacobson [1910] . . .	Ox kidney .	67·12	11·54	2·84	2·18	2·9 : 1	"Carnaubon."
MacLean [1912, 2] .	Horse kidney	68·19	12·37	3·00	3·44	1·93 : 1	—
,, [1913] .	Ox heart .	—	—	3·07	3·41	1·99 : 1	—
Thudichum [1884] .	Brain .	67·01	11·35	3·00	3·23	2 : 1	Apomyelin.
,, ,, .	,, .	65·37	11·29	2·96	3·24	2 : 1	Sphingomyelin.
,, ,, .	,, .	62·4	—	—	—	—	Amidomyelin.

184° to 185°, while a mixture of both "melted" at 183° to 184° [MacLean, 1913]. The most satisfactory test of purity is absence of carbohydrate material indicating absence of cerebrosides.

Chief Properties of Sphingomyelin.

The properties of sphingomyelin have been described by Thudichum [1884], Rosenheim and Tebb [1908; 1909, 1; 1910], Stern and Thierfelder [1907], and Levene [1913; 1914; 1916].

Sphingomyelin is a white non-hygroscopic stable substance which crystallises from alcohol in the form of tables or needles arranged in star-like formations. It can be easily pulverised to form a white powder, not unlike stearic acid in appearance, but rather firmer and harder. On exposure to air and light, sphingomyelin undergoes no change. It dissolves to a very slight extent in cold alcohol but very easily on heating; from its hot alcohol solution sphingomyelin separates on cooling in crystalline form. In cold or hot ether it is practically insoluble, but dissolves easily on warming in chloroform, benzene, pyridine and glacial acetic acid. In cold acetone it is insoluble, but dissolves to a certain extent in hot acetone.

Sano [1922, 1] obtained a specimen containing 3·78 per cent. phosphorus which melted at 196° to 198°.

With water, sphingomyelin forms an opalescent starch-like mixture from which it is precipitated by acetone. It forms compounds with cadmium chloride, platinum chloride, and lead acetate. When quite pure it gives no carbohydrate reaction. On treatment with nitrous acid by Van Slyke's method no nitrogen is evolved, indicating the absence of free amino nitrogen in the molecule. Dissolved in glacial acetic acid and alcohol, sphingomyelin absorbs hydrogen. For an

impure specimen the iodine value was found to be 34·3 [Stern and Thierfelder]. Sphingomyelin is dextro-rotatory, material from different sources having about the same specific rotation as shown by the following figures given by Levene [1916] :—

Source of Sphingomyelin.	Solvent.	Concentration.	Temperature.	$[\alpha]^D$ Value.
Brain .	Chloroform and methyl alcohol 1 : 1	About 8 per cent.	25°	+ 8·20
,, .	,, ,, ,,	,, ,,	25°	+ 8·20
,, .	,, ,, ,,	,, ,,	25°	+ 7·53
,, .	,, ,, ,,	,, ,,	25°	+ 7·52
Kidney	,, ,, ,,	,, ,,	36°	+ 8·73
Liver .	,, ,, ,,	,, ,,	32°	+ 7·61
Egg-yolk	,, ,, ,,	,, ,,	25°	+ 7·54

According to Sano [1922, 1] a change in the rotatory power of sphingomyelin in pyridine solution takes place at 40° C., corresponding to a change in the solubility of the compound.

CHAPTER III.

OCCURRENCE, METHODS OF EXTRACTION, ISOLATION, AND PURIFICATION OF PHOSPHOLIPINS.

Occurrence of Phospholipins in the Tissues.

HOPPE-SEYLER [1867] made the observation that when egg-yolk was treated with ether until no more extract could be obtained, the egg-yolk residue still contained phospholipins which could be removed by treatment with warm alcohol. Subsequent investigators [Erlandsen, 1907; Cohn, 1911] have confirmed this observation, and it is now generally recognised [Schulze and Steiger, 1889] that the same phenomenon is met with in all tissues, both animal and plant. Thus, in extracting dried healthy kidneys with ether not more than 15 per cent. to 30 per cent. of the total fats and lipins, and often less than this, can be obtained. On subsequent treatment with alcohol the remainder comes out with ease. Heart, liver, pancreas, muscle, blood, milk and various body fluids, etc., all behave in the same way. No matter how long the ether extraction is persevered with, a large percentage of the phospholipins still remains in the tissue.

Attempts have been made to explain this phenomenon on the supposition that the ether fails to penetrate the tissues—that the difficulty is simply a mechanical one. It has been pointed out that when fats or phospholipins are mixed with protein matter and the whole mass dried and then extracted with ether, only a fraction of the added ether-soluble material is removed. While this is true to a degree, it is equally certain that the fraction which can be removed bears a much higher proportion to the total fatty matter than is the case in extraction of the tissues.

Again, if the organ extracted is not a healthy specimen but one suffering from marked fatty degeneration, the greater part of the phospholipins is obtained by ether extraction.

From this it would appear that part, at any rate, of the phospholipin material is present in some kind of combination with the proteins which is insoluble in ether. When the combination is acted

on by alcohol, the phospholipin is liberated and is then readily extracted by alcohol, in so far as mechanical difficulties permit. In this connexion an interesting observation was made by Osborne and Wakeman [1915]. In an investigation on the lecithin of milk, they found that the phospholipins were present in the precipitated protein matter. On drying this precipitate and extracting it with ether, no lipin whatever was obtained, while subsequent treatment with alcohol removed a considerable amount. The lipins were obtained from the alcoholic washings of the casein, from the coagulum produced by boiling the acid filtrate from the casein and from the precipitate produced by neutralising the filtrate from the heat-coagulable proteins. Wherever protein was found, lipin appeared to be associated with it [Osborne and Wakeman, 1916].

The exact nature of this association-complex between lecithin and protein is not known. Hoppe-Seyler advanced evidence in support of the view that part of the lecithin of egg-yolk was in direct chemical combination with protein. Others, on the other hand, believe that the association is dependent on physical phenomena [Mayer and Terroine, 1907; Fischer and Hooker, 1916], and the latter view is generally held.

The combination of phospholipins with cell protein explains the difficulty encountered in attempting to stain many normal tissues for fat. In the case of the normal kidney, for instance, no fatty material can be demonstrated by any of the ordinary staining methods, but if the kidney is one showing signs of fatty degeneration, then fat can be easily demonstrated and stains well. In the latter case the lipins which are naturally in combination are in the free state and give the ordinary staining reactions of fats, while under normal circumstances the combined form is present and gives no reaction with fatty stains.[1] The heart muscle of guinea-pig, when stained with the usual fat-staining reagents, shows no sign of the presence of fat in the cell. Twenty-four hours after the injection of diphtheria toxin, the granules within the cell are readily stained, and the cells appear charged with fatty globules. Yet both specimens of muscle on chemical analysis may yield the same amount of fat [Dudgeon, 1906]. In true "fatty infiltration" the ether extract of the tissue contains large amounts of neutral fats and fatty acids, but only the normal amount of lipins; in "fatty degeneration," on the other hand, the combined lipins are set free so that nearly all the fatty material is removed by ether

[1] See also Fischer and Hooker [1916].

extraction. The serious significance of "fatty degeneration" as against "fatty infiltration" is thus obvious, seeing that the former condition implies the disintegration of the cell tissue, whereas infiltration generally indicates some difficulty on the part of the cell to deal with reserve fat. No doubt, in many cases, the primary defect in cellular activity is progressive and leads to true degeneration, but fatty infiltration of itself is not necessarily associated with lessened activity; on the other hand, fatty degeneration is inconsistent with the continuance of the functional activity of the cell.

Judging from experimental results, it would appear that much of the *essential* fatty matter of cells is in lipin form and is chiefly composed of lecithin and kephalin in intimate association with the cell protein. This essential "fat" appears to be necessary for the survival of the cell, since it is preserved under circumstances of extreme emaciation. Mayer and Schaeffer [1913, 1914] have carried out an elaborate series of investigations in order to determine the ratio between the different "lipoid" constituents of each tissue; they desired to establish and find out whether this ratio is constant and specific for each tissue; whether, in fact, the functions of the cells of the different tissues can be correlated with a certain definite proportion between the various cell constituents, viz. fatty acids, cholesterol and lipoid phosphorus. They have traced the changes which occur in rabbits during starvation, and have shown that the proportion of lipoid phosphorus in the dry matter of the cell does not diminish but actually tends to increase, notably so in the lung. Lipin is universally present in all living cells, and forms an indispensable part of the actual living matter of the cell. It is possible that it forms a stage in the elaboration of fat to more complicated compounds, but of this we know nothing with certainty [Hammersten, 1904; MacLean and Williams, 1909].

Amount and Estimation of Phospholipins in the Tissues.

Various attempts to estimate the lecithin (phospholipin) content of tissues have been made. From the nature of the problem, however, we are still without any reliable information on this point, since no method giving satisfactory results has as yet been evolved. Attempts to isolate and weigh the phospholipin as such are attended with much loss, so that the figures are generally too low. By this method Erlandsen [1907] obtained from dried ox heart from 7 to 10 per cent., from egg-yolk Roaf and Edie [1905] obtained 9·5 per cent. of lecithin,

while Manasse [1906] obtained a similar figure. It is probable that the proportion of lecithin present in egg-yolk varies very considerably and is dependent on several factors [MacLean, 1909, 1; Tornani, 1909].

For various tissues hardened in formaldehyde Cruickshank [1913, 1] obtained the following numbers for 100 grms. of wet substance :—

Ox heart	0·36 grm.
,, kidney	0·48 ,,
,, spleen	0·14 ,,
,, lungs	0·40 ,,
,, testicles	0·62 ,,
,, thyroid	0·30 ,,
,, pancreas	0·68 ,,
,, submaxillary	0·30 ,,
,, red corpuscles	3·50 grms.
Sheep red corpuscles	0·12 grm.
Human brain	0·60 ,,

The majority of the results obtained in attempts to estimate the phospholipin content of tissues have been arrived at by extracting the tissue with suitable organic solvents and estimating the phosphorus content of the more or less purified extract. From this the amount of "lecithin" is reckoned on the assumption that lecithin contains about 4 per cent. of phosphorus. An attempt to estimate separately the amount of lecithin and kephalin in the tissues was made by Koch and Woods [1905], but almost all investigators have simply extracted the mixture of phospholipins present and called the extract "lecithin."

Unfortunately there are various indications that phosphorus-containing bodies other than lipins are extracted along with the phospholipins, so that at best the method gives only very rough indications. Probably the suggestion of Collison [1912] that the solvents used should be water-free is of value, but even then it is difficult to get the tissues absolutely water-free. A general idea of the figures so obtained is furnished by the table on the opposite page, quoted from Nerking [1908].

The determination of the amount of lipins present in the body glands has led to the interesting result that certain of the ductless glands contain a high proportion of lipins compared with tissues such as muscle-fibre. This is especially marked in the suprarenals and pituitary body, and to a somewhat less extent in the pineal gland, the

	Percentage of Lecithin in "Wet" and Dried Tissues of *Cat.*		Percentage of Lecithin in "Wet" and Dried Tissues of *Rabbit.*		Percentage of Lecithin in "Wet" and Dried Tissues of *Hedgehog.*	
	"Wet" Tissues.	Dried Tissues.	"Wet" Tissues.	Dried Tissues.	"Wet" Tissues.	Dried Tissues.
Lung . .	1·36	6·10	1·52	5·96	0·85	4·28
Heart . .	1·27	4·55	1·60	5·86	2·09	10·49
Brain . .	4·48	13·74	3·86	12·41	4·18	22·31
Cord . .	9·52	26·20	11·16	35·18	6·47	18·19
Kidney . .	1·69	6·26	1·34	5·02	1·88	8·55
Spleen . .	0·09	0·39	1·19	4·23	1·44	6·56
Eye . .	—	—	0·35	2·19	—	—
Liver . .	1·09	4·99	1·07	3·82	1·45	5·23
Stomach . .	—	—	0·88	3·31	1·11	6·37
Intestines .	—	—	0·21	0·62	0·24	1·50
Blood . .	—	—	0·14	0·86	—	—
Muscle . .	—	—	0·60	2·59	1·00	3·71
Bone marrow .	—	—	2·71	—	41·7	—
Bone . .	—	—	0·18	0·27	0·59	0·87
Skin . .	—	—	0·20	0·48	0·35	0·58
Suprarenals .	1·98	5·36	2·39	5·54	21·23	92
Testicles . .	—	—	1·03	3·39	1·92	11·27

infant thymus, and the corpus luteum of pregnancy in its early stage. The proportion of lipins in the thyroid is, however, low [Fenger, 1916]. Young tissues seem to be particularly rich in lipins; this is noticeable in the spinal cord of young animals, the amount of lipin decreasing with age [Glikin, 1907]. The bodies of young animals contain a much higher percentage of alcohol-soluble phosphorus than those of the old, and the high lipin value of the corpus luteum in the early stages of pregnancy may either be an accompaniment of the active growing tissue or may be related with the specific secretory activity of the cells [Corner, 1917]. Other interesting observations on the distribution of lipins in the nervous system of animals at different ages have been made by Lorrain Smith and Mair [1913].

Mayer and Schaeffer [1914; 1914, 1] give the following figures for the tissues of the normal rabbit:—

	Dried Tissue.		"Wet" Tissue.	
	P. Per Cent.	Lecithin. Per Cent.	P. Per Cent.	Lecithin. Per Cent.
Liver . . .	0·54	13·5	0·142	3·54
Kidney . . .	0·54	13·5	0·122	3·05
Lung . . .	0·49	12·2	0·096	2·40
Muscle . . .	0·17	4·2	0·039	0·98

A large number of estimations for different organs have been carried out, but, as may be seen by comparing the two tables given

above, the results are so variable that no purpose is served by giving figures. Among these investigations may be mentioned investigations on the brain and spinal cord [Fränkel, 1909; Fränkel and Linnert, 1910, 2; Fränkel and Dimitz, 1910], bone marrow [Glikin, 1907; Otolski, 1907; Bolle, 1910; Bernazky, 1908], heart muscle [Rosenbloom, 1913, 1], lung [Sieber, 1909; Sammartino, 1921], suprarenals [Mulon, 1903; Bernard, Bigart and Labbé, 1903], ovaries [Parhon, Dumitresco and Nissipesco, 1909; Serano and Palozzi, 1915; Faure-Fremiet, 1915; Iscovesco, 1912], fish sperm [Sano, 1922], fæces [Long, 1906; Long and Johnson, 1906], placenta [Bienenfeld, 1912] and other tissues [Gerard and Verhaeghe, 1911].

The question of the lecithin content of milk has naturally engaged considerable attention. Milk as food for the young might be expected to contain much phospholipin, but this is not the case. In fact, more than one observer has argued that it contained no phospholipin whatever, but it is now certain that a small amount is present. Nerking and Haensel [1908] found 0·024 to 0·079 per cent. in human milk and 0·13 to 0·17 per cent. in cow's milk. Reference has already been made to the work of Osborne and Wakeman [1915; 1916]; they found that small amounts of lipin occurred in cow's milk, forming 0·27 per cent. of the whole milk. The fact that the small amount of lipin present is so closely associated with the protein may account for the failure of several investigators to detect its presence. Other observations on milk phospholipins are by Tolmatscheff [1867], Stoklasa [1897], Burow [1900], Bordas and Raczowski [1902], Koch and Woods [1905], Koch [1906], Glikin [1909], Njegovan [1910, 1913], Fränkel [1911], Brodrich-Pittard [1914], and Hess and Helman [1925]. An attempt by Wrampelmayer [1893] to distinguish between margarine and butter by estimating the lecithin content of the latter was unsuccessful.

The amount and distribution of the lipins in blood has been the subject of many investigations.[1] Nerking [1908] found marked differences in the lecithin content of the blood of certain animals. According to Bürger and Beumer [1913] very little lecithin is present in human blood, and in that of the sheep; sphingomyelin is most abundant and then kephalin. The subject of the phosphorus metabolism of the body has recently occupied an increasing share of attention and has led to the appearance of a number of methods for estimating the phosphorus in small quantities of blood, which have been applied for the estimation of the lipin phosphoric acid. Such methods have

[1] See Bloor [1915, 1; 1916; 1916, 1], Bloor, Joslin and Hornor [1916], Dinkin and Klein [1914] and Grimbert and Laudat [1912].

been described by Taylor and Miller [1914], Greenwald [1915], Bloor [1915, 1918], Lemeland [1921], Bell and Doisy [1920], Briggs [1922], and Whitehorn [1924]. Both Greenwald and Bloor rely for the actual determination on the estimation of the turbidity of the solution, the strychnine molybdate reagent of Pouget and Chouchak [1909] being used to precipitate the phosphate; in the Bell and Doisy method the phosphate is estimated colorimetrically.

Bloor has carried out a large number of determinations of the lipin content of blood; he takes as lipin, the fraction, soluble in a mixture of alcohol and ether, which is precipitated together with the protein by dilute acids. His most recent results indicate that the lipoid content of the corpuscles is fairly constant, the average being about 0·40 gr. per 100 c.c. of blood. In the plasma the percentage of lipin is much lower than in the corpuscles, and very much more variable, the average figure being about 0·22 per cent.

Methods of Extraction, Isolation and Purification of Phospholipins.

Many of the principles governing the extraction of phospholipins from the tissues will be obvious from the above remarks. It is clear that extraction by ether alone is unsuitable, since only a small amount of the phospholipin material is dissolved. Practically all the methods, both old and new, depend on the employment of ether and alcohol. Riedel [1912] recommended the use of methyl alcohol. The more important of the older methods will be referred to, and after the general principles have been explained, the individual phospholipins —lecithin, kephalin and sphingomyelin—will be treated in detail.

Older Methods of Obtaining Phospholipins (Lecithin).

In the earlier attempts to obtain lecithin [1] great difficulty was experienced in the separation of this substance from fats and cholesterol owing to the common solubility of all these substances. This difficulty was to a great extent overcome by taking advantage of Hoppe-Seyler's observation already described. Hoppe-Seyler [1867] and Parke [1867] thoroughly extracted egg-yolk with ether and treated the residue with warm alcohol. The alcohol extract obtained was concentrated, and on cooling gave a precipitate of a substance containing nitrogen and phosphorus which Hoppe-Seyler considered to be lecithin. The latter observer states that this lecithin was obtained by him in crystalline

[1] The only phosphatide considered was lecithin.

form as fine glistening needles, but subsequent observers have failed to secure this result. From the method of preparation it is quite certain that this lecithin must have contained an excess of kephalin; the latter substance is much less soluble in alcohol than lecithin, and would thus tend to fall out on cooling. It is therefore difficult to understand how crystals of phospholipin could have been obtained, and it seems more probable that Hoppe-Seyler's lecithin crystals were crystals of fat or fatty acids which contaminated the lecithin.

This method of obtaining lecithin was employed by Diaconow [1868, 3], whose work on the chemical constitution of lecithin was carried out on a substance isolated according to Hoppe Seyler's principles. Diaconow used egg-yolk, and after extracting with ether, cooled the subsequent alcohol extract to — 10° or so. He thus obtained what he considered to be pure lecithin. A similar method was used in the preparation of lecithin from brain [Diaconow, 1868].

Strecker [1868], who also carried out an important investigation on the structure of lecithin, obtained his substance in a different way. Strecker added platinum chloride to the alcohol-ether extract of egg-yolk and precipitated the phospholipin as the platinum combination. This compound was dissolved in ether, precipitated by alcohol several times, and the lecithin separated from the purified product by hydrogen sulphide.

Gilson [1888] prepared lecithin from the *ethereal* extract of egg-yolk by evaporating off the ether, dissolving the residue in petroleum ether and washing the petroleum ether solution in a separating funnel with several changes of 75 per cent. alcohol. On allowing the alcohol solutions to stand in a cool place, a precipitate settled out which was filtered off. The solution was then decolorised by means of animal charcoal, the alcohol evaporated and the residue taken up with ether. The ethereal solution was filtered, evaporated to dryness, and the residue taken up in a very small amount of alcohol. On evaporation at low temperature lecithin was obtained.

Thudichum [1884] obtained lecithin from brain by a very complicated method. The brain was extracted with warm alcohol, and the alcohol extract, after undergoing various processes, treated with cadmium chloride. The cadmium chloride compound was thoroughly exhausted with ether and the ether-insoluble residue treated with cold benzene. The part soluble in cold benzene Thudichum recognised as lecithin cadmium chloride, and from this "lecithin hydrochlorate" was separated by sulphuretted hydrogen. This "lecithin

hydrochlorate" was separated as a felted mass of crystals. This sample must have been true lecithin with the whole of its nitrogen present in the form of choline, since extensive preliminary precautions were taken to get rid of kephalin; any kephalin precipitated by the cadmium chloride would have been dissolved out by the treatment of the cadmium compound with ether. Indeed, Thudichum mentions that "the quantity of the platinum salt obtained was very near to that which should have been obtained if all the nitrogen had existed in one form in lecithin and had been obtained in one form."

All these methods were unsatisfactory, and many of them exceedingly tedious as well. Also the manipulation necessary in some of them could not have failed to produce changes in such a labile substance as lecithin. The isolation of phospholipins in a pure form was rendered much simpler by the important discovery of Zuelzer [1899] that phospholipins were insoluble in acetone.[1] By this medium the ether or alcohol extract of a tissue can be easily separated from ordinary fats, fatty acids and cholesterol. In all investigations subsequent to Zuelzer's observation acetone has been used in the separation of phospholipins. Of the older methods the only important remaining one is that of Bergell.

Bergell [1900] extracted egg-yolk for six hours with boiling 96 per cent. alcohol under a reflux condenser. After cooling to 0°, an alcoholic solution of cadmium chloride was added, the mixture allowed to stand for some hours, the precipitate separated and washed with 96 per cent. alcohol. The precipitate was then dried in air, extracted with ether, and boiled under a reflux condenser with eight times its volume of 80 per cent. alcohol. Ammonium carbonate in concentrated solution was gradually added to the boiling mixture until the fluid was alkaline, and a test portion showed the filtrate to be cadmium-free. During the addition of ammonium carbonate the flask was thoroughly shaken. On completion of the reaction, the solution was filtered hot and the filtrate gradually cooled to — 10° C. The resulting precipitate was taken up in chloroform, precipitated with acetone and dried *in vacuo* over sulphuric acid.

This method has been used with certain modifications by Schulze and Winterstein [1903], Hundeshagen [1883], Lüdecke [1905], MacLean [1915] and others, but is objected to by certain investigators on the ground that the lecithin is decomposed on treatment with cadmium

[1] Probably this fact was known before Zuelzer's observation, but he was the first to adopt it for practical purposes.

chloride with the liberation of part of the fatty acids [Erlandsen, 1907; Eppler, 1913].

The N : P ratio of Bergell's lecithin was exactly 1 : 1, the nitrogen being 1·74 per cent. and the phosphorus 3·75 per cent. As these agree with the average figures found for lecithin, it would not appear that much decomposition had taken place [Thierfelder]. This point was, however, submitted to careful investigation by Levene and West [1918]) who were able definitely to show that lecithin was recovered unchanged from its cadmium chloride compound.

Recent Methods for Obtaining Phospholipins.

In all the later methods for obtaining phospholipins the tissue is first freed from macroscopic fat and then dried. Owing to the labile nature of certain of the phospholipins and the ease with which oxidation of their unsaturated fatty acids takes place, the problem of drying is not so simple as at first sight it might appear. The easiest way to get rid of water is to expose the pulped tissue to a high temperature in an oven or water-bath, and this method has been actually adopted by certain investigators. Such methods, however, are quite inadmissible in dealing with phospholipins. The objects to be aimed at are to get the tissue dried in the shortest possible time with the minimum of exposure to air and at the lowest temperature that can be conveniently employed. Only in this way can one hope to isolate phospholipins in an unchanged condition.

Methods of Drying Tissues.

Drying in Air.

Erlandsen [1907] dried minced heart tissue by spreading out the finely minced material in a thin film on a glass plate. The temperature was raised to about 30° by means of Bunsen burners, and a current of air generated by an ordinary electric fan made to play over the material. When dry, the substance was broken into small fragments and passed through a grinding machine; the process of drying was completed by putting the powder obtained into an evacuated desiccator containing sulphuric acid.

This is a very efficient method for dealing with tissues or egg-yolk, and quite a considerable amount of material can be dried in a comparatively short time. The process is greatly accelerated if the material is broken up at intervals, since a skin tends to form on

the surface which prevents further drying. For fear of setting up decomposition the temperature should not exceed 30°. In cases where the substance to be dried contains a great deal of fat, it may be necessary to treat it with alcohol or ether after drying and prior to reducing it to powder. This method has been used successfully by Stern and Thierfelder for egg-yolk [1907], by MacLean for egg-yolk, heart and kidney tissue [1909; 1912, 2] and by others. The chief objection to its use appears to be the possibility of autolytic processes taking place. The conditions are suited both for autolysis and for the development of bacteria, and it is uncertain whether some decomposition and oxidation may not occur in certain cases. Probably in investigations which require quite unchanged substances one of the following methods is preferable. The plan suggested by Cruickshank [1913], in which the tissues are fixed with formaldehyde previous to extraction, is likely to produce changes in the lipins and possesses no obvious advantages.

Drying in Vacuo.

Where suitable apparatus is available for drying the minced tissue *in vacuo*, this method possesses obvious advantages over drying in air. There is less danger of oxidation, but it is possible that the action of the autolytic enzymes of the tissues is more completely prevented by drying by means of dehydrating solvents. Levene has found the method of drying *in vacuo* gives good results.

Drying by Alcohol.

The tissue after being thoroughly pulped is covered with several times its volume of alcohol. The mixture is well stirred, allowed to stand for a short time, and the liquid separated by filtration through a cloth. The residue thus obtained is packed up in sail cloth and subjected to pressure by means of a laboratory hand press; by this means almost all the alcohol is squeezed out. A firm cake remains, which after drying at room temperature under the fan for half an hour or so can be ground into powder and extracted with ether or other solvent. The alcohol used for drying is diluted considerably by the water of the tissues, and this aqueous alcohol does not remove much phospholipin.

Drying by Acetone.

This is perhaps the best method of all, and has been used by Fränkel, Parnas and others. Theoretically, acetone has an advantage

over alcohol in that the former solvent dissolves fats and cholesterol, but leaves the phospholipins behind. Practically, it is found that acetone is capable of removing some phospholipin, for lecithin is soluble to a marked extent in acetone which contains fatty substances in solution [Erlandsen, 1907; MacLean, 1914, 1]. Under the conditions generally employed the amount removed is small, but if boiling acetone is used, as was the case in Fränkel's work, considerable amounts of phospholipins are dissolved. By the use of acetone at ordinary temperature a tissue may be freed from water, and at the same time fats and cholesterol dissolved out, the only fatty bodies left behind being the lipins. Acetone is used in the same way as alcohol.

Drying by Anhydrous Salts.

When certain anhydrous salts are rubbed up intimately with moist tissue, water is taken up and the hydrated salt formed. In this way a dry powder can be obtained which is suitable for extraction by the usual solvents. Anhydrous sodium sulphate has been employed for this purpose by Pinkus [1901] and Schryver [1906]; Rosenheim [1906] used the calcium salt. According to Fränkel and Elfer [1910; 1912] anhydrous sodium phosphate is preferable both to sodium and calcium sulphates. This method has the disadvantage that large amounts of the anhydrous salts are required to give a dry mixture, but is suitable for drying small amounts of tissue; when large amounts have to be dealt with, as is generally the case in phospholipin investigations, the dried mass obtained is so voluminous as to render the method impracticable. Calcium carbide has been recommended by Rosenbloom [1913], but for obvious reasons it can hardly be recommended.

Extraction and Isolation of Phospholipins from Dried Material.

The material which has been dried by one of the above processes is now thoroughly extracted with a suitable solvent. For this purpose ether and alcohol are the solvents generally employed. Sometimes the dried material is first exhausted with ether and the residue subsequently extracted with alcohol. This method was used by Erlandsen [1907] and considered by him to be necessary, since this investigator found that the phospholipins removed by the ether were different from those found in the subsequent alcohol extract. This observation of Erlandsen was found to be erroneous, and MacLean [1913] has

shown that the phospholipins in the alcohol extract are the same as those of the ether extract. Thus in cases where it is convenient to employ alcohol alone as a solvent there are no objections to its use.

Levene [1921] recommends the use of acetone which, in the presence of fat, extracts principally unchanged lecithin and kephalin; the extraction is incomplete, but this solvent is useful when pure samples of lecithin or kephalin are to be prepared.

Whatever plan is adopted, the resulting extract contains not only phospholipins but fat, fatty acids, cholesterol and other substances as well.

In an ether extract the phospholipins which may be present are lecithin and kephalin with their decomposition products and sphingomyelin; certain of the decomposition products of kephalin are insoluble in alcohol, and are absent therefore from the alcoholic extract. Kephalin, though soluble in ether, is generally regarded as being insoluble in alcohol; though very sparingly soluble in cold alcohol, it is soluble in hot alcohol. Possibly the presence of other fatty matters renders it still more soluble in this solvent; at any rate, the alcohol extract of a tissue invariably contains a certain amount of kephalin. Sphingomyelin, though practically insoluble in pure ether, is fairly soluble in an ethereal extract of lecithin; it is somewhat soluble in cold alcohol and easily soluble in warm alcohol. Its presence in both ether and alcohol extracts is thus explained.

Levene and Simms [1921] recommend the successive extractions of the tissue with acetone, ether, and alcohol, the extracts being separately worked up.

General Principles of Separation of Phospholipins from Associated Substances.

After thorough extraction of the tissue, the extract is concentrated and the residue treated with ether when a thick opalescent mixture is obtained. The insoluble fraction consists partly of impurities, such as inorganic salts and a nitrogenous substance to be described later, and partly of sphingomyelin and cerebrosides. This ether-insoluble part is separated either by filtration or by centrifuging, leaving a clear yellowish ether solution. This solution is concentrated and treated with excess of acetone, which precipitates the phospholipins, leaving cholesterol and fats in solution. On redissolving the precipitate in ether, a slightly opalescent solution is again obtained; the opalescence

is due to the presence of small amounts of a mixture of sphingomyelin and cerebrosides. On centrifuging, the liquid yields a clear solution which is concentrated and precipitated with acetone as before. The precipitated phospholipins are now comparatively free from cholesterol, fat, fatty acids and sphingomyelin; by several repetitions of the above process of dissolving in ether and precipitating with acetone, every trace of these impurities is ultimately got rid of. The phospholipin mixture isolated in this way is dissolved in a small amount of ether, and excess of absolute alcohol added. The addition of alcohol causes some of the phospholipins to separate; this alcohol-insoluble part constitutes crude kephalin. The alcohol-soluble part when further purified yields a substance with a nitrogen and phosphorus percentage corresponding to that of lecithin and is considered to be lecithin.

Many modifications of the above processes may be introduced to suit particular cases, but the essential manipulations are always the same. The isolation of the individual phospholipins in a pure state is described later.

Nature of the Impurities Associated with the Phospholipins.

Two kinds of impurities are commonly found accompanying the phospholipins; both are insoluble in acetone, and are therefore precipitated by acetone from the ether solution. One of these is soluble in ether, but insoluble in alcohol, and is distinguished by a high phosphorus content; the other is insoluble in ether, but soluble in alcohol, and has a high nitrogen content. They were described as new phospholipins by Erlandsen [1907], who obtained them by the following method. Dried heart tissue was extracted with several changes of ether till little or no residue remained on evaporating the ether. On extracting the residue with alcohol a substance was obtained which was not lecithin. This substance was isolated as a cadmium chloride combination, and was described as a diaminomonophosphatide. The ethereal extract, on the other hand, contained lecithin, as was to be expected, together with an alcohol-insoluble lipin, which had all the properties of kephalin. On analysis it was found, contrary to expectation, that this body differed in composition from kephalin, since its N : P ratio was not 1 : 1 as in kephalin, but 1 : 2. To this substance Erlandsen gave the name cuorin.

Levene and Komatsu [1919] have shown that in this so-called cuorin were contained various hydrolytic decomposition products of

kephalin, for the latter substance readily loses both its unsaturated fatty acid radicle and its base, and leaves substances richer in phosphorus than the original kephalin (cp. Chapter II, p. 51). The nature of the supposed diaminomonophosphatide obtained in the alcoholic extract was elucidated by MacLean, who showed that a hitherto undetected nitrogenous substance was present.

In the course of an investigation on horse kidney, MacLean [1912, 2] found that the phospholipins of the primary ether extract were of the same nature as those described by Erlandsen for heart muscle, but that the phospholipin of the alcohol extract contained very variable amounts of nitrogen and gave N : P ratios varying from 4 : 1 to 1·5 : 1. This suggested that the phospholipin present was contaminated by a substance or substances containing a high percentage of nitrogen, and that some light might be thrown on the nature of this phospholipin if it could be separated from the nitrogenous substance. This impurity gave almost all the ordinary reactions of phospholipins, so that all earlier attempts failed to bring about complete separation, though material changes in the N : P ratio were effected. Finally, it was found that repeated emulsification of the alcohol phospholipin mixture with water, followed by the addition of a small amount of acetone, resulted in a purification of the phospholipin, and on analysis the N : P ratio proved to be the same as that of lecithin—1 : 1. The purified substance gave all the ordinary lecithin reactions. There was therefore no doubt that the phospholipin present in horse kidneys, which was extracted by alcohol after preliminary treatment with ether was of the same nature as the lecithin obtained in the preliminary ether extract—a monoamino-monophospholipin. Similar experiments carried out on heart muscle gave identical results, indicating that Erlandsen's diaminomonophosphatide was simply impure lecithin [MacLean, 1913]. The nitrogenous impurity, which is always present in alcohol extracts of organs, is satisfactorily separated only by the method described. The substance is responsible for certain of the alleged new phospholipins, many of which are nothing more than lecithin contaminated with this product. The nature of this contaminating substance is unknown, and it is no doubt a mixture, though from its general properties a good deal of some body representing a chemical unit must be present. How far it is formed as the result of decomposition processes in the tissue is unknown, but this factor probably plays a part. As it will be necessary to refer to this substance on several occasions, some term to designate it is

almost essential. For purposes of reference the writers will in future pages refer to this nitrogenous impurity as "Carnithin"—a name which is provisionally suggested merely for reasons of expediency and with no relation to its chemical composition. Some properties of this body are given below.

Carnithin.

Carnithin is obtained from the phospholipin fraction present in the alcohol extract of the tissues. On emulsifying the impure phospholipin mass with water and then adding acetone, the phospholipins separate, leaving behind a slightly brownish fluid. On evaporating this fluid carnithin is left behind as a soft sticky syrupy residue. Carnithin is insoluble in ether and in *absolute* alcohol, but easily soluble in alcohol containing traces of water. It is exceedingly soluble in water; on standing for some days an aqueous solution gradually deposits small round white crystals. These crystals are insoluble in cold water, but dissolve in boiling water, and are reprecipitated on cooling. After recrystallisation in this way several times, a substance or mixture of substances is obtained which has a very high nitrogen content and appears to belong to the purine class of bodies. In one case small round concentric white crystals having all the properties ascribed to carnine were isolated. After drying at 105° this crystalline substance was found to contain 28·55 per cent. nitrogen. On heating it changed colour at about 230° and blackened at 240°. With silver nitrate a white flocculent precipitate was obtained which did not dissolve in ammonia or nitric acid. A precipitate was also given with basic lead acetate and with mercuric chloride, but not with lead acetate nor with mercuric nitrate. In another sample of carnithin a small amount of a substance which appeared to be impure hypoxanthine was isolated; it contained about 40 per cent. of nitrogen. The mother liquor from which these substances separate is distinctly acid in reaction, and it is probable that these bodies are set free by a process of decomposition and are not present in the free state in the original liquid. This is suggested by their extreme insolubility in cold water, and the difficulty experienced in re-dissolving them in the mother liquor after separation has once taken place. The fact that complete separation takes several days, or even weeks, is also suggestive in this connexion.

Owing to the high nitrogen percentage in these bodies, it is obvious that the presence of a small quantity of this impurity in lecithin would

materially raise the nitrogen percentage and considerably modify the N : P ratio. When the separation of these products is complete, an absolutely clear straw-coloured mother liquor is obtained which remains clear for a very long time. On evaporating to dryness, a sticky hard gum-like substance remains. This body, which dissolves in alcohol containing some moisture, is also soluble in solutions of lecithin. *Further, like phospholipins in general, it is precipitated by acetone, by cadmium chloride and also by platinum chloride.* Its cadmium chloride salt is soluble in warm benzene, but is precipitated from this solution by absolute alcohol. The substance appears to be of a very complex nature, and so far no clue as to its chemical composition has been obtained. Different specimens were found to contain on an average about 6 per cent. of nitrogen, and there is generally a small amount of phosphorus also present, though the latter may not amount to more than a trace and may even be absent. When tested by Van Slyke's method a considerable part of its nitrogen was evolved. On hydrolysis some specimens yielded a small amount of fatty acids, but this was probably due to contamination with lecithin, since a specimen has been obtained which when boiled with hydrochloric acid for several hours gave no trace of fatty acids. It decolorised Fehling's solution on heating but no precipitate occurred; on prolonged boiling, however, a dense precipitate was formed. Attempts to fractionate this body showed that it contained a substance which gave the reactions of creatinin.

Carnithin, though quite insoluble in pure ether, is easily soluble in an ethereal solution of lecithin, so that this body cannot be separated from lecithin by ether extraction; the same holds good for alcohol. From descriptions of the methods employed by several investigators, it is quite obvious that many of the supposedly pure phospholipins isolated must have been contaminated with this impurity.

Detailed Methods for Isolation and Purification of the Individual Phospholipins.

The general principles on which the isolation of phospholipins is based are sufficiently indicated above. Various modifications and extensions may be introduced to suit particular circumstances, and there is no single method which can be claimed to give the best results in all cases. Details of one method for the isolation of each of the principal phospholipins are given below, as it was thought that this

plan might be helpful to anyone attempting to prepare phospholipins for the first time and having no practical experience of these bodies. It is obvious, however, that all the phospholipins may be isolated at the same time from the same tissue.

I.

Preparation of Lecithin [MacLean, 1914].[1]

In the preparation of lecithin the most suitable solvent to use is alcohol, though of course ether may also be employed. The various steps in the process are as follows :—

1. The tissue used (heart, kidneys, egg-yolk, etc.) is, in the case of solid organs, ground to a fine paste by a mincing machine and dried by one of the methods described. On the whole, it is perhaps preferable to dry the tissue by means of acetone, but alcohol or the air process may be used. Whatever method is employed, the resulting product is passed through a coffee mill and ground to a fine powder.

2. The dried powder is thoroughly extracted several times (generally four to six) with excess of absolute alcohol. The best way to do this is to use large well-stoppered bottles, and to shake the mixture of alcohol and tissue by means of a shaking machine. After shaking for two to three hours the bottle is removed, and left to stand for some time, when the bulk of the alcohol can be decanted off. It is not necessary that the separated alcohol should be quite clear. Sometimes the bottle containing the alcohol and tissue is filled with carbon dioxide to prevent oxidation as far as possible. If any difficulty is experienced in separating the alcohol, the mixture may be filtered either through a cloth or filter paper. The latter process is rather slow and is seldom necessary; if, however, it should be used filtration may be facilitated by the use of the suction pump. In ordinary cases all that is necessary is to decant as much alcohol as possible and pass the remainder through a suitable cloth. This, of course, gives an opalescent fluid, but there does not seem to be any special advantage in getting a clear filtrate at this stage. The various extracts are mixed and preserved in well-stoppered bottles. On completion of extraction the mixed alcoholic extracts are concentrated to small bulk under reduced pressure at 40°.

3. The residue is taken up with a small volume of ether in which much of it remains insoluble. To the mixture, without any attempt at filtration, acetone is added in excess and the resulting precipitate

[1] The method described here is a slight modification of that published in the "Journal of Pathology and Bacteriology," 18, p. 490.

pounded together by a pestle and separated. The precipitate is again mixed with ether, precipitated by acetone and treated as before. By this process, which is repeated three or four times, all but traces of acetone-soluble bodies are removed.

4. The precipitate from above is rubbed up in a mortar with a large excess of water and a good emulsion made; to the emulsion from one-quarter to one-half its volume of acetone is added. On the addition of the acetone a large amount of substance separates in the form of large white flakes which float on the surface of the liquid. This is removed, partly by means of a glass spatula and partly by filtration through a filter paper perforated by small holes. It is again emulsified and precipitated three times more. In order to get the phospholipins to separate well it is advisable to add a little sodium chloride to the aqueous emulsion prior to the addition of the acetone; indeed, the *emulsification* can be carried out with water containing a little sodium chloride, and in this case the phospholipins always separate very easily.

The filtrate obtained from the first emulsification always contains much soluble matter—inorganic salts and the nitrogenous impurity already referred to (carnithin)—but after the first treatment only traces of carnithin are found in the liquid.

The solid substance which separates is now dried by treating it several times with fresh additions of acetone. Finally, as much acetone as possible is pressed out of the mass by means of a pestle, and the whole taken up in ether in which it is still partly insoluble, forming an opalescent mixture.

5. The ether mixture is centrifuged when a clear supernatant fluid and a white precipitate are obtained. This white precipitate is impure sphingomyelin. The ethereal solution is decanted off and treated with excess of acetone. The resulting precipitate is again taken up in ether, when an almost clear solution should be obtained. Centrifuging is repeated as before, and the clear supernatant ethereal solution again precipitated with acetone. Generally, it is only necessary to centrifuge twice, but if the phospholipin is not quite soluble in ether after a second treatment, the process must be repeated until a precipitate is obtained which is quite soluble in this solvent. If a centrifuge is not available separation may be accomplished by allowing the mixture to stand for some time in narrow tall cylinders; the solid part gradually falls to the bottom and the ether can be decanted off. Ordinary filtration is not very successful in these cases.

6. The substance is now dissolved in alcohol, and if the solution is not quite clear it is allowed to stand for some time until the insoluble substance (crude kephalin) settles on the bottom of the flask. The amount of alcohol-soluble substance obtained depends on circumstances to be explained later. After separation of the bulk of the alcohol-insoluble part by decantation, the solution is filtered.

7. The clear alcohol solution is now concentrated under reduced pressure at 40° until all the alcohol is removed. The residue is taken up in ether and the phospholipin separated from the ethereal solution by acetone. The precipitate obtained should give a perfectly clear solution with ether and with alcohol. It is finally treated with several changes of acetone and dried in a desiccator *in vacuo* over sulphuric acid.

This substance is a mixture of true lecithin and kephalin, and should show on analysis about 1·8 per cent. of nitrogen and 4 per cent. of phosphorus, giving a nitrogen : phosphorus ratio of approximately 1 : 1. The separation of pure lecithin from this mixture has already been described. The alcoholic solution is treated with a saturated alcoholic solution of cadmium chloride; the resulting precipitate is washed with ether and recrystallised from ethyl acetate until it gives no reaction for amino-nitrogen. The purified cadmium chloride compound is suspended in 80 per cent. alcohol, and the boiling mixture treated with finely powdered ammonium carbonate until it is alkaline to litmus. Finally, the cooled alcoholic solution of pure lecithin is filtered and concentrated *in vacuo* [Bergell, 1900].

Anomalous Results Obtained in the Preparation of Lecithin.

When a tissue is treated as above described a good deal of alcohol-insoluble phospholipin (kephalin) is usually obtained (see paragraph 6). It, however, the same kind of tissue is procured in *as fresh a condition as possible and quickly dried*, it is often found that the phospholipin ultimately obtained is entirely soluble in a small amount of alcohol. In this case the whole of the extracted phospholipin, since it is soluble in alcohol, would be held to be lecithin. Now these divergent results can be obtained from the same tissue, so that according to the treatment of the material, one observer may find nothing but lecithin while another may find abundance of both lecithin and kephalin. Again, it very often happens that lecithin which dissolves easily in alcohol immediately after its separation from the tissues becomes partly insoluble in alcohol, even when preserved in a carefully evacuated

brown glass desiccator. The alcohol-insoluble substance formed has the properties and composition of kephalin. This change in solubility is much more in evidence if the organic solvents employed are not quite pure, and in general the greater care taken to purify the various organic reagents (ether, acetone, etc.) the more lecithin is obtained. Particularly does this appear to be the case with ether; it is probable that this action of ether is due to the oxidising effect of some impurity in the ether on the kephalin part of the so-called lecithin. In one experiment bearing on this point, heart tissue was extracted with alcohol in the usual way, and the phospholipin taken up in ordinary good ether as supplied by the dealers. Another portion was treated in exactly the same way, ether from the same source being used, but only after careful purification. Using ordinary ether a considerable amount of the phospholipin ultimately obtained was insoluble in alcohol, and part of the "lecithin" fraction became alcohol-insoluble after a week. On the other hand, the specimen in which the purified ether was used gave nearly all "lecithin" which when tested six weeks after preparation was found to be quite soluble in alcohol. From these anomalous results it is easy to explain the divergence of opinion with regard to the occurrence of kephalin in the tissues. Thus Erlandsen [1907] could find no trace of kephalin in heart muscle, while Koch and Woods [1905] found more kephalin than lecithin.

Preparation of Lecithin from Egg-yolk.

Levene and Rolf [1921] use a somewhat simpler method for the preparation of pure lecithin. Dried egg powder is exhaustively extracted by acetone: the extract is concentrated to a small bulk and left for 24 hours at 0°. The fat which separates is filtered off and melted on the water-bath with from two to three times its volume of alcohol: the liquids are mixed and allowed to crystallise at 0°. The mother liquor is concentrated under diminished pressure to half its original volume and an alcoholic solution of cadmium chloride added until no further precipitation occurs. The powdered cadmium salt is suspended in its own volume of toluene to which a few drops of water have been added. If the solution is opalescent, it is centrifuged to remove cerebrosides and the clear toluene solution poured into 4 volumes of ether containing 1 per cent. of water. The precipitated cadmium lecithin compound is separated by means of the centrifuge, dissolved in chloroform, and the free lecithin liberated by means of a solution of ammonia in methyl alcohol.

II.

Preparation of Kephalin [Parnas, 1909].

Parnas used petroleum ether for the preparation of kephalin on the ground that it extracts less of certain decomposition products of the tissue, and is obtained in a dryer condition than ether. This investigator extracted his kephalin from brain according to the following plan :—

1. Fresh brain was rubbed up with acetone and made into a fine pulp. To the finely divided brain substance three times its weight of acetone was added, and the whole left to stand for ten days; the hardened material was then separated from the acetone and spread cut in a thin layer under a fan at 30°; this treatment dried it completely in less than one hour.

2. The dried mass was ground to a fine powder and extracted for a whole day with five times its weight of low boiling petroleum ether (b.p. 30° to 60°); the extraction was facilitated by the use of a shaking machine. After separation of the extract, fresh petroleum ether was added and the process repeated several times. The extracts were completely separated from residual material by the centrifuge. During the centrifuging a good deal of cooling naturally took place which caused the separation of large amounts of galactolipins.

3. The combined extracts were concentrated at ordinary pressure as long as the temperature remained below 50° and then under diminished pressure. Some low boiling-point petroleum ether was then added; on strong suction being applied this easily evaporated, and as a result the mixture was cooled down to — 20°, whereby large amounts of galactolipins fell out.

4. The decanted liquid was further concentrated and precipitated with excess of alcohol. The precipitate was washed with alcohol, dissolved in petroleum ether and again treated with alcohol. The precipitate was then washed and dried *in vacuo*. This mass consisted of impure kephalin.

5. The kephalin was left to stand *in vacuo* for from ten to fourteen days; it was then powdered and shaken with five times its weight of cold ether. The mixture was centrifuged and the clear solution obtained left to stand in ice for twenty-four hours. After again centrifuging, the kephalin was precipitated by the addition of alcohol.

6. The kephalin was now purified by dissolving in ether and washing the solution with weak hydrochloric acid till calcium was

no longer present in the acid. The ethereal solution was then washed several times with water, followed by weak soda and again by water. The purified kephalin was obtained from the ether solution by precipitation with alcohol. For other methods of purification see Levene and Rolf [1922].

III.

Preparation of Sphingomyelin [Levene, 1914; 1916].

Sphingomyelin can be very easily obtained free from other phospholipins owing to its slight solubility in alcohol and ether, but its separation from the galactolipins, which constantly accompany it in the tissue, is a matter of great difficulty. The isolation of sphingomyelin in a pure form was rendered much easier by the observation of Rosenheim and Tebb [1910, 1] that a mixture of sphingomyelin and galactolipins could be separated by means of pyridine. This solvent is now invariably used in the preparation of sphingomyelin. A pure sample of this body should give no carbohydrate reaction on hydrolysis, and the absence of such a reaction is taken as an indication of its purity.

Levene [1914] gave explicit directions for the preparation of the pure substance, but showed later that the body obtained by this method was not quite pure. By a modification of his former process he now claims to be able to isolate pure sphingomyelin [Levene, 1916].

Since sphingomyelin contains no unsaturated fatty acids and does not appear to be influenced by exposure to air, it is not necessary to take such precautions in the drying of the tissue as is necessary in the case of the other phospholipins. Levene obtained pure sphingomyelin by the following steps :—

1. Desiccated brain tissue was exhaustively extracted with boiling alcohol, each extraction lasting about thirty minutes. On cooling this extract a precipitate formed.

2. The precipitate was thoroughly extracted with ether and acetone.

3. The residue was dissolved in hot technical pyridine and allowed to cool; after standing for some time a precipitate formed.

4. The precipitate was dissolved in hot glacial acetic acid and allowed to cool, when a deposit occurred. The mother liquor which contained sphingomyelin was concentrated under diminished pressure and transferred into acetone, when crude sphingomyelin was precipitated.

5. The crude sphingomyelin was dissolved in a mixture of 5 parts ligroin and 1 part alcohol. Alcohol (98 per cent.) was added as long as a precipitate formed. The filtrate was then allowed to stand overnight at 0° and again filtered. The final filtrate was concentrated under diminished pressure and poured into acetone.

The purity of the material obtained at this stage depended largely on the nature of the ligroin employed for solution, though the poorest specimens obtained were as pure as Thudichum's sphingomyelin.

6. The material obtained in this manner was further purified by recrystallisation from a solution consisting of equal parts of pyridine and chloroform. This was carried out in several stages. Five recrystallisations were made at room temperature; these were followed by recrystallisation at 30° and finally at 37°. The recrystallisations were continued until the substance gave a negative orcin test in the presence of a trace of copper acetate. The substance ultimately obtained was pure sphingomyelin.

CHAPTER IV.

THE GALACTOLIPINS.

(SYNONYMS: CEREBROSIDES (THUDICHUM), GALACTOSIDES (ROSENHEIM), CEREBRO-GALACTOSIDES (THUDICHUM).)

Nomenclature.

THE term cerebrosides was used by Thudichum [1874] to designate certain phosphorus-free lipin bodies of a glucoside nature which he had succeeded in isolating from the brain. On hydrolysis these bodies yielded amongst other products a reducing sugar, the nature of which Thudichum did not at first recognise. To this sugar he gave the name "cerebrose," and following the usual nomenclature of the glucosides suggested that these lipin compounds which furnished this sugar should be called cerebrosides. Later, when it was recognised that "cerebrose" was really galactose, Thudichum suggested that the term cerebro-galactosides might be a more suitable name for this class of bodies. Rosenheim [1913] proposed that the general term "galactosides" should be used to designate these substances. Since, however, the galactosides include a large number of bodies having no necessary connexion with lipins, it is of importance to have a somewhat more specific term to indicate these lipin products. Such a term is Thudichum's "cerebro-galactosides," but at best this is rather a clumsy combination, and though useful is by no means an ideal designation. Perhaps the most satisfactory name yet suggested is that of galactolipins, introduced by Leathes. This indicates the relation of these bodies to the phospholipins, and at the same time shows that they are differentiated from the latter by the presence of galactose and the absence of phosphorus in the molecule.

For our more recent knowledge of the cerebrosides we are chiefly indebted to the researches of Thierfelder [1890-1915], who was the first, after Thudichum, to undertake a systematic investigation of these substances. Valuable contributions have also been made by

Levene and his collaborators [1912-1916] and by Rosenheim [1913-1916].

Historical.

The first phosphorus-free lipin extracted from the brain was isolated by Müller [1858], who called his product cerebrin. Previous to Müller's discovery the nearest approach to a substance resembling cerebrin was probably a body, containing 0·52 per cent. of phosphorus, obtained by von Bibra. Müller's cerebrin, which was entirely free from phosphorus, was isolated from brain which had been mixed with baryta water and boiled; the coagulum formed was extracted with hot alcohol, the alcoholic extract allowed to cool, and the resulting precipitate washed with ether to remove fat and cholesterol. The residue was again recrystallised from boiling alcohol, when a light white powder without taste or smell, and having the empirical formula $C_{34}H_{33}NO_6$, was obtained.

Bourgoin [1874], by a process of fractional crystallisation at different temperatures, isolated a somewhat similar body from protagon; this product, however, contained less nitrogen than Müller's cerebrin. Köhler [1867] claimed to have obtained nitrogen-free cerebrins. Up to this time nothing was known as to the constitution or decomposition products of cerebrin, but in 1874 a remarkable paper by Thudichum [1874] appeared, by which our knowledge of the phosphorus-free group of lipins, and, incidentally, of many other lipins, was materially advanced. This publication was so fundamental and far reaching that only in quite recent years has anything of moment been added to the observations which Thudichum then recorded. This work was probably the finest contribution ever made to lipin chemistry, and yet for many years it was treated with cold neglect. Thus, in a paper on cerebrin by Geoghegan [1879] five years later, there is no reference to Thudichum's epoch-making results.

Thudichum recognised that the phosphorus-free bodies present in brain were analogous in their constitution to the vegetable glucosides, and distinguished two chief representatives of this class—phrenosin and kerasin.

Since phrenosin is relatively easy to prepare in large amount, Thudichum succeeded in elucidating its composition by a study of its hydrolytic cleavage products. Kerasin, though more difficult to isolate, was also very successfully investigated by him. It is important to note that recent research has shown that other galactolipins,

differing in the nature of the fatty acid radicles, may be present in the tissues. Up to quite recent times, investigators paid too much attention to slight differences in the elementary composition or physical properties of galactolipin-like bodies obtained by them, with the result that the literature contains a copious list of supposedly new substances. These bodies, which received such names as cerebrin [Müller, 1858; Parcus, 1881; Kossel and Freytag, 1893; Cruto, 1922], homocerebrin [Parcus, 1881], entkephalin [Parcus, 1881], pseudo-cerebrin [Gamgee, 1880], cerebron [Thierfelder, 1904], *d*-cerebrine [Levene and Jacobs, 1912, 2] were nothing more than Thudichum's phrenosin or kerasin or mixtures of these two bodies. It must be admitted that some of these substances, such as Thierfelder's cerebron, were much purer products than Thudichum ever succeeded in isolating.

It is now customary, following the suggestion of Posner and Gies [1905] and of Rosenheim [1909], to designate the individual galactolipins in terms of Thudichum's names—phrenosin and kerasin—rather than by any of the other terms mentioned.

GENERAL PROPERTIES OF THE GALACTOLIPINS.

The galactolipins are bodies of a glucoside nature which on hydrolysis furnish a reducing sugar (galactose), a base (sphingosine) and a fatty acid.

The fatty acid present in phrenosin differs from that in kerasin, a fact which helps to explain certain differences in the properties of these two closely related bodies [Thudichum, 1874; Rosenheim, 1916]. Their general similarity of composition is well seen by a comparison of their decomposition products :—

PHRENOSIN	(1) Fatty acid	= Phrenosinic acid ($C_{25}H_{50}O_3$).
	(2) Carbohydrate	= Galactose.
	(3) Base	= Sphingosine.
KERASIN	(1) Fatty acid	= Lignoceric acid ($C_{24}H_{48}O_2$).
	(2) Carbohydrate	= Galactose.
	(3) Base	= Sphingosine.

These bodies possess many of the properties of sphingomyelin, particularly with regard to solubility in alcohol, a fact that renders the fractionation of mixtures of these products very difficult. Sphingomyelin is rather more soluble in cold absolute alcohol and less soluble in cold pyridine than the galactolipins, a property which is taken advantage of in their separation. When dry, the galactolipins are white and " more or less opaque, but are capable of becoming in part transparent like wax. They are deposited from alcoholic solutions in minute microscopic particles, which may be termed crystalline, but have no claim to be termed crystallised. These particles are arranged in various composite forms—balls or branched masses or rosettes " [Thudichum, 1884]. Under special conditions true crystals of *phrenosin* can be obtained [Wörner and Thierfelder, 1900; Rosenheim, 1914, 1], but so far no one has succeeded in obtaining true crystals of kerasin.

The galactolipins dissolve easily in hot alcohol, from which they are deposited on cooling. In cold absolute alcohol and in cold benzene they are practically insoluble; in hot benzene they dissolve easily, and are deposited on cooling as a gelatinous mass. The addition of cold alcohol to a hot benzene solution precipitates the galactolipins in the form of white flakes. In ether, cold or hot, they are almost insoluble. They dissolve readily in pyridine at 30°, but are insoluble in cold acetone. From hot alcoholic or hot acetone solutions, the phrenosin constituent is first precipitated on cooling, and it is only at a temperature below that at which the most of the phrenosin separates that

kerasin begins to fall out. The separation of the two galactolipins from each other is based on this property.

The galactolipins in common with sphingomyelin have the property of forming " liquid crystals " at certain temperatures, a phenomenon which accounts for many of the discrepant statements with regard to the melting-point of these substances recorded in the literature [Rosenheim, 1914, 1].

The galactolipins are optically active bodies, phrenosin being dextro-rotatory and kerasin lævo-rotatory.

On account of the presence of sphingosine and galactose in the molecule, the galactolipins give certain colour reactions. Thus when rubbed up with concentrated sulphuric acid the particles gradually take on a deep purple-red colour, while in the presence of cane sugar and concentrated sulphuric acid the purple colour appears immediately.

The orcin reaction which is given by galactolipins, as pointed out by Fränkel and Linnert [1910, 1], is dependent on galactose and not on the presence of pentose, as these observers thought [Levene, 1907].

PHRENOSIN.

Thudichum obtained phrenosin by extracting brain with 85 per cent. alcohol at 45°. The "white matter" which deposited on cooling was treated with ether to remove lecithin and kephalin, and the residue recrystallised several times from alcohol. Further separation of such bodies as "myelin" and "cerebrinic acid" was carried out by treatment with lead acetate followed by ammonia and lead acetate until the hot alcoholic solution gave no precipitate on addition of these reagents. The product obtained at this stage was dissolved in hot absolute alcohol, and the processes of solution and recrystallisation repeated "a great number of times" until the mother liquor gave no further precipitate with cadmium chloride. The precipitate caused by cadmium chloride was due to sphingomyelin, which was to a large extent removed by this treatment. The residue now consisted largely of a mixture of phrenosin and kerasin, which were partly separated by fractional recrystallisation. The mixture was dissolved in hot alcohol which on cooling began to deposit rosettes of phrenosin at from 50° to 40°. When the temperature reached 28° this precipitation ceased, and the supernatant liquor remained clear until the temperature fell to 26°. Below this temperature a gelatinous cloudy mass appeared which floated on the phrenosin and consisted mainly of kerasin. Isolation of phrenosin was therefore accomplished by allowing the hot alcoholic solution of mixed cerebrosides to cool to 28°, when the precipitate which formed was separated. This product was mainly phrenosin, and on further recrystallisation in the same way gave a substance containing only 0·113 per cent. of phosphorus. Kerasin from the mother liquor had 0·198 per cent. of phosphorus. Both these substances also contained inorganic salts. Thudichum never succeeded in getting his products quite free from phosphorus, despite the number of solutions and recrystallisations to which they were subjected. In the case of phrenosin, further treatment with cadmium chloride. ether and sulphuretted hydrogen decreased the phosphorus content to 0·048 per cent. Three analyses of this phrenosin gave the following results :—

No.	C.	H.	N.	O.
1	67·71	11·62	2·15	18·51
2	67·89	11·42	2·13	18·56
3	67·67	11·23	2·07	19·03
Average . .	67·75	11·42	2·11	18·70

Hydrolysis furnished as decomposition products a carbohydrate (cerebrose), a base (sphingosine), and a fatty acid (neurostearic acid).

Carbohydrate Radicle of Phrenosin.

Galactose = Cerebrose (Thudichum).

The " cerebrose " which Thudichum obtained from phrenosin by boiling with dilute sulphuric acid had the formula $C_6H_{12}O_6$ and separated in crystalline form. Previous to Thudichum's researches indications of the presence of a carbohydrate complex in certain brain lipins were obtained by Baeyer and Liebreich [1867], who showed that protagon yielded a sugar which had many of the properties of glucose. They considered that this sugar was present in glucoside formation.

Thudichum thought that cerebrose was a new hexose isomer, but it was shown by Thierfelder [1890], and immediately afterwards by Brown and Morris [1890] that cerebrose was identical with galactose.

Base of Phrenosin.

SPHINGOSINE.

From phrenosin Thudichum [1881, 1] isolated a base which he identified as a body of the composition $C_{17}H_{35}NO_2$; to this product he gave the name sphingosine (see p. 58). The correctness of Thudichum's observations was substantiated by Thierfelder [1904], who isolated sphingosine from cerebron; it was only after he had completely worked out the constitution of this base that Thierfelder became aware of Thudichum's observations. The results of these observers agreed very closely, and they both arrived at the same empirical formula. The presence of sphingosine in kerasin has been shown by several later observers.

Fatty Acid of Phrenosin.

PHRENOSINIC ACID [NEUROSTEARIC ACID (THUDICHUM), CEREBRONIC ACID (THIERFELDER)].

The fatty acid of phrenosin, like its other constituents, was first investigated by Thudichum [1881, 1], who isolated from the hydrolytic products of phrenosin a fatty acid resembling stearic acid. This product was separated in crystalline form, and on analysis gave the following figures :—

C 75·88 per cent.
H 12·85 ,, ,,
O 11·27 ,, ,,

This percentage composition agreed very closely with that required for stearic acid ($C_{18}H_{36}O_2$), and its close relationship to stearic acid was further substantiated by an investigation of its corresponding ethyl ester, which had the empirical formula $C_2H_5(C_{18}H_{35}O_2)$. So far the data obtained were the same as those furnished by stearic acid, but that the product was not stearic acid was recognised by Thudichum, who showed that its melting-point was 84° to 85° as against 69·3° for stearic acid. This observer came to the conclusion that the acid of phrenosin was an isomer of ordinary stearic acid, and he designated it neuro-stearic acid.

Thudichum failed to recognise the real constitution of this acid, and to Thierfelder [1904] belongs the credit of having shown that Thudichum's neurostearic acid was really an hydroxy-acid of the formula $C_{25}H_{50}O_3$. This hydroxypentacosanic acid Thierfelder obtained from " cerebrone," and for this reason he called it " cerebronic " acid. Since " cerebrone " was simply a purer form of phrenosin than Thudichum had succeeded in isolating, there is no doubt that " cerebronic " acid and " neurostearic " acid were identical substances. Both products were prepared by similar methods, and Thierfelder's specimen yielded on analysis figures very close to those obtained by Thudichum :—

Cerebronic Acid.

C = 75·33
H = 12·50
O = 12·17

In spite of this, Thierfelder [1905, 1] declined to admit the identity of the two acids; for this view he had apparently good reasons, since cerebronic acid melted at 98° to 99°, while neurostearic acid melted at 84° to 85°.

This anomaly was satisfactorily explained by Levene and Jacobs [1912, 1], who again obtained Thudichum's acid of low melting-point (82° to 85°). These observers showed that cerebronic acid exists in two optically isomeric states, of which the inactive *d-l* form melts at 82° to 85° and represents Thudichum's neurostearic acid, while the dextro-rotatory form melts at 106° to 108°. Thierfelder's cerebronic acid was therefore a mixture of the two forms in which the optically

active compound predominated. The conditions under which these two isomers are formed have not yet been ascertained, and there does not appear to be any definite proof that the whole of the acid constituent of phrenosin is not originally present in the optically active form. In the isolation and hydrolysis of phrenosin, racemisation might possibly take place, so that in spite of certain results obtained by Levene and Jacobs [1912, 2], indicating that different isomers actually exist preformed in phrenosin, the matter is still undecided.

Rosenheim [1916] found that the melting-point of the dextrorotatory acid was lowered considerably by keeping it for some time in a toluene bath, and suggested that the change in melting-point might be due to the formation of an anhydride or lactone-like derivative. The presence of an hydroxyl group in the acid lends support to this view; this change, if it takes place, would explain the difficulties encountered by Levene and West [1913] in obtaining correct titration values for the inactive acid. The existence of these different isomers may explain the results of Grey [1913], who isolated from brain three hydroxy acids with different melting-points, though the existence of other hydroxy acids is not excluded.

Thierfelder has not yet accepted the validity of Levene's observations, but maintains [Brigl, 1915] that the differences between cerebronic acid (m.p. *circa* 98° to 100°) isolated by him, and Levene's acid (m.p. *circa* 82° to 85°) are dependent not on stereo-isomerism, but on *structural* isomerism. Thierfelder and Brigl adopt the view that phrenosin (cerebron) gives rise on hydrolysis to two structurally isomeric acids, one of which is cerebronic acid and the other an acid similar to the one obtained by Thudichum [1881, 1] and by Levene and Jacobs [1912, 1]. To this latter acid they gave the name neuric acid (neurosäure). According to this view, phrenosin contains two optically active isomeric pentacosanic acids differing in structure.

This assumption is not in accord with the fact that the same sample of phrenosin yields a cerebronic acid of different melting-point and of different optical power depending on the conditions of hydrolysis [Levene and West, 1916, 4; Rosenheim, 1916].

Further, Levene and West [1916, 4] showed that on oxidation with permanganate solution, both "cerebronic acid" (m.p. 99° to 100° $[\alpha]_D^{20} = +2{\cdot}6$) and "neuric acid" (m.p. 86° $[\alpha]_D^{20} = +1{\cdot}5$) yielded the same tetracosanic acid melting at 81°. If the original acids were different in structure, it is difficult to imagine that both would yield an identical tetracosanic acid. For the present, therefore, it would

seem that Levene and West's conception that "cerebronic" and "neuric" acids are structurally identical, and that the differences between them are dependent on optical isomerism, is the most probable explanation of the anomalies described.

Since the name phrenosin is now in general use it is best to call the acid derived from it *phrenosinic* acid [Posner and Gies, 1905; Rosenheim, 1914] instead of cerebronic or neuro-stearic acid.

Structure and Properties of Phrenosinic Acid.

Though Thierfelder showed that this acid had the empirical composition $C_{25}H_{50}O_3$, and that one hydroxyl group was present, he did not ascertain the position of this hydroxyl group, nor did he furnish any evidence as to the manner in which the carbon atoms were linked together. Indeed, the percentage composition of carbon and hydrogen on which Thierfelder relied for his formula is of itself hardly sufficient, in the case of the higher fatty acids, to indicate the number of carbon atoms actually present in the molecule: the "acid value" of the substance furnishes a surer clue.

The position of the hydroxyl group was established by Levene and Jacobs [1912, 1], who showed that cerebronic acid when oxidised with alkaline permanganate solution [Edmed, 1898] gave rise to an acid of the constitution $C_{24}H_{48}O_2$. The hydroxyl group must therefore have been attached to the carbon atom next to the carboxyl group—the α-carbon atom. That the carbon chain was an open or normal one was made probable by the transformation of phrenosinic acid into a hydrocarbon that melted between 54° to 57°.

According to Krafft [1882] the three hydrocarbons $C_{24}H_{50}$, $C_{25}H_{52}$, $C_{26}H_{54}$ have the melting-points 51°, 53·5° and 58° respectively. Since the melting-point of the hydrocarbon of phrenosinic acid was in the region of that obtained from the hydrocarbon $C_{25}H_{52}$, it seemed very probable that this substance also had the composition $C_{25}H_{52}$. This assumption was further substantiated by the fact that the acid value for pure phrenosinic acid corresponds to the molecular weight value of $C_{25}H_{50}O_3$ [Levene and Jacobs, 1912, 1].

In the light of this evidence, Levene and Jacobs at this time suggested that phrenosinic acid was the normal α-hydroxylpentacosanic acid $CH_3 . (CH_2)_{22} . CH(OH) . COOH$, but later they modified this view. Thierfelder believes that cerebronic acid corresponds to the normal hydroxy acid, and in the hope of obtaining evidence in

support of this contention Brigl [1915], working in Thierfelder's laboratory, prepared normal α-hydroxypentacosanic acid and compared its melting-point with that of cerebronic acid. The results were inconclusive, the figures obtained being as follows :—

	M.P.
(*a*) Cerebronic acid	= 100° to 101°
(*b*) *r*-Cerebronic acid	= 97° ,, 100°
(*c*) Synthetic n. α-Hydroxypentacosanic acid	= 102° ,, 104°
(*d*) Mixture of (*b*) and (*c*) . . .	= 98° ,, 100°

Interesting evidence as to the nature of the carbon chain of phrenosinic acid was obtained by Levene [Levene and Jacobs, 1912, 1 ; Levene, 1913 ; Levene and West, 1913, 1913, 1], who showed that the acid $C_{24}H_{48}O_2$ obtained on oxidation of phrenosinic acid was really lignoceric acid, as it had the same melting-point (81°) and furnished the same derivatives [Hell and Hermanns, 1880 ; Kreiling, 1888] as this acid.

Since the melting-point of the hydrocarbon obtained on reduction of lignoceric acid was 51°, and agreed with that given in the literature for the normal tetracosane, Levene and West [1913, 1] concluded that lignoceric acid possessed a normal carbon chain.

About this time Meyer, Brod and Soyka [1913] showed that lignoceric acid was not identical but isomeric with the normal tetracosanic acid, since a sample of the synthetical normal acid melted at 85·5° to 86° while lignoceric acid melted at 81°. This was corroborated by Levene, who prepared a similar normal product which melted at 87·5° to 88° [Levene and West, 1913, 1 ; Levene, West, Allen and Scheer, 1915].

Since Levene had based his view of the constitution of lignoceric acid on the similarity of the melting-point of the hydrocarbon derivative with that of the normal pentacosane (51°) [Marie, 1896], he set out to re-investigate this point, and found that instead of melting at 51° the normal hydrocarbon melted at 55°. Levene therefore abandoned his original view of the structure of lignoceric acid, and agreed that it was isomeric but not identical with the normal tetracosanic acid.

Since lignoceric acid was easily derived from phrenosinic acid, it followed that phrenosinic acid also had a branched carbon chain [Levene and West, 1914, 1].

From Levene's observations on the relationship of lignoceric and phrenosinic acids it seems highly probable that phrenosinic acid

($C_{23}H_{47}$. CH(OH) . COOH) is the α-hydroxy derivative of the next higher homologue of lignoceric acid.

Conclusive proof of this was furnished by Levene and Taylor [1922], who oxidised phrenosinic (cerebronic) acid to the corresponding tetracosanic acid, and from this built up a α-hydroxypentacosanic acid. Lignoceric acid was converted by a similar series of changes into the α-hydroxypentacosanic acid, and the two acids thus prepared were found to be identical. Not only did the melting-points of the acids correspond (92·5° C.), but the melting-points of the corresponding substances in each series, which were obtained as intermediate stages in the preparation of the two specimens of acid, as well as the melting-points of their mixtures, were identical. As an additional proof, lignoceric acid was itself converted to phrenosinic acid, and the latter was shown to be identical with that obtained from phrenosin. In view of Levene's results, phrenosinic acid must be regarded as hydroxy-lignoceropentacosanic acid.

The identification of the α-hydroxypentacosanic acid melting at 84° to 85° obtained by Thudichum and by Levene and Jacobs and Levene and West needs further investigation.

Brigl and Fuchs [1922] have described the isolation of two tetracosanic acids from beechwood tar, the normal one, melting at 85° C., and a lower melting one melting at 75°, and suggested that lignoceric acid melting at 80° to 81° was really a mixture of these two isomers. Levene, Taylor and Haller [1924] prepared samples of lignoceric acid from peanut oil and from the kerasin of cattle brains. Both starting materials yielded an acid melting at 80° to 81°, and no separation into components could be achieved by subjecting it to the process used by Brigl and Fuchs to separate their acid into its components. It seems therefore to be definitely established that lignoceric acid is a pure substance melting at 80° to 81° and isomeric with normal tetracosanic acid.

Phrenosinic acid is a snow-white easily powdered non-hygroscopic substance soluble in ether and in warm alcohol [Thierfelder, 1904]. It crystallises from alcohol or ether in characteristic "mamillary" or "cauliflower-like" masses [Thudichum, 1881, 1] which, under the polarising microscope, are seen to consist of irregular sphero-crystals. These crystals behave to the selenite plate test exactly as the mother substance phrenosin [Rosenheim, 1916].

As already indicated, the acid exists in two conditions—the racemic and optically active forms.

Constitution of Phrenosin.

From the results of various observers it is now certain that phrenosin contains only the three components already mentioned, and possesses the empirical formula $C_{48}H_{93}O_9N$ [Thierfelder, 1905]. This contention is strongly supported by the figures obtained on elementary analysis. Three highly purified specimens of phrenosin examined by Rosenheim [1916] furnished the following data :—

No.	1.	2.	3.	Average.	Calculated for $C_{48}H_{93}O_9N$.
C	69·78	69·69	69·34	69·60	69·65
H	11·63	11·29	11·11	11·34	11·24
N	1·90	1·79	1·91	1·83	1·70

Though there are various ways in which these constituents of phrenosin might be linked together, the possible arrangements have been considerably narrowed down, with the result that a probable formula for this substance can now be given with a good deal of confidence.

The following observations relating to the individual components of phrenosin help to show the manner in which these different bodies must be linked together in the molecule.

1. The hydroxyl group of phrenosinic acid is free. This assertion is based on the fact that phrenosin forms a hexa-acetyl derivative, which contains one more acetyl group than the corresponding product from kerasin. Since the only difference between phrenosin and kerasin is in the fatty acid, which in phrenosin has one hydroxyl group, it must be this hydroxyl group which gives the extra acetyl group. In order to do this the hydroxyl group must be free [Thierfelder, 1914, 1]. Further support is also accorded to this view by the work of Pryde and Humphreys [1924], who methylated phrenosin and kerasin, using Irvine's method; they found that kerasin yields a pentamethyl derivative, but phrenosin a derivative intermediate between penta- and hexa-methyl.

2. The NH_2 group of sphingosine,

$$C_{12}H_{25} . CH : CH . CH(OH) . CH(OH) . CH_2(NH_2),$$

is not free, since when tested for free amino nitrogen in Van Slyke's apparatus no nitrogen could be obtained from cerebrosides [Levene and Jacobs, 1912, 2]. The fact that phrenosin has neither an acid nor an alkaline reaction is strong evidence that phrenosinic acid and

sphingosine are united through the carboxyl and amino groups—R . CO—NH . R'—as in the case of the amino acids in protein [Thierfelder, 1914, 1].

From the fact that along with sphingosine some dimethyl-sphingosine is also formed during hydrolysis of phrenosin in methylic alcohol solution, it may be inferred that both the hydroxyl groups of sphingosine are at least partly combined with the other groups [Rosenheim, 1913, 1; 1916; Thierfelder, 1914, 1].

3. From our knowledge of the structure of the naturally occurring galactosides it may be assumed that, like these, phrenosin is a β-galactoside. Thus one of the hydroxyl groups of the sphingosine is combined through the aldehyde carbon of the galactose in the usual way [Rosenheim, 1913, 1]. That the aldehyde group of galactose is not present in the free form is evident, since phrenosin possesses no reducing properties [Thierfelder, 1914, 1].

According to Thierfelder, another of the hydroxyl groups of galactose is also in combination with sphingosine. This is unlikely, for if it were so we might expect to get some alkyl galactose on alcoholysis [Rosenheim, 1916].

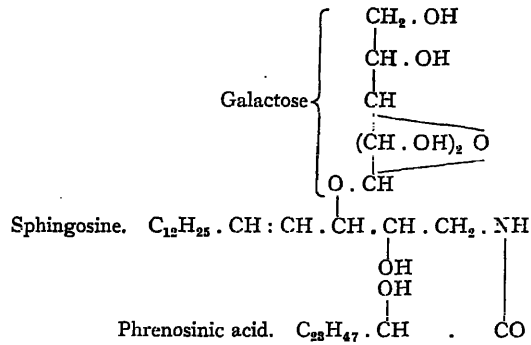
Rosenheim suggested that partial anhydride formation probably takes place between the sphingosine and phrenosinic acid hydroxyls, but that such linkage can only be partial is apparent from the fact already stated, that the phrenosinic acid hydroxyl is readily acetylated.

This assumption of anhydride formation furnishes a satisfactory explanation for the existence of the two modifications of phrenosin (p. 105). The ordinary "amorphous" phrenosin corresponds to the anhydride formula, while in the crystallised phrenosin the two hydroxyl groups are free. This view receives support from the observation that crystallised phrenosin contains 1 molecule of water more than the amorphous modification [Wörner and Thierfelder, 1900; Rosenheim, 1914, 1].

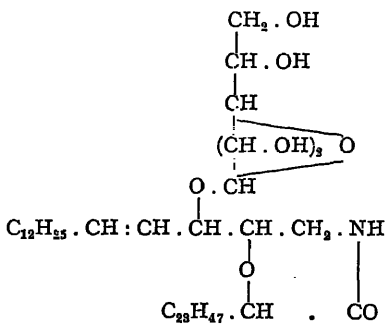
Rosenheim points out that if this view is correct, the completely crystallised phrenosin should give rise to a monoalkyl sphingosine, and suggests that a substance isolated by Thomas and Thierfelder [1912] from a sample of "cerebron" and which these observers first considered as a monomethyl-sphingosine did really contain monomethyl-sphingosine together with ordinary sphingosine.

On the bases of these observations the following constitutional formula for phrenosin ($C_{48}H_{95}O_9N$) has been suggested [Rosenheim, 1916]:—

CRYSTALLISED PHRENOSIN.



AMORPHOUS PHRENOSIN.



Though these formulæ are in conformity with the results so far obtained in chemical investigations of phrenosin, they are by no means put forward as final. The results of partial hydrolysis of this compound, either by enzyme action or by other means, should furnish conclusive evidence as to the correctness of these formulæ; in this connexion it is interesting to observe that Thudichum long ago obtained evidence of the existence of hydrolytic intermediate compounds. One of these, which was galactose-free phrenosin, he called *æsthesin*, while to the other, which was phrenosin minus phrenosinic acid, he gave the name *psychosin*. Thierfelder [1914] also obtained galactose-free products from phrenosin. Phrenosin does not appear to be easily acted on by enzymes, for it resists the action both of pancreatic lipase and emulsin [Rosenheim, 1916].

Some Physical Properties of Phrenosin.

Liquid Crystals and True Crystals of Phrenosin.

In continuation of the work of Rosenheim and Tebb on protagon [1908] and of Lorrain Smith and Mair [1910, 1] on galactolipins,

Rosenheim [1914] showed that phrenosin can exist in the state of liquid crystals. Phrenosin, as usually obtained, consists of a white so-called crystalline powder, which does not possess any true crystalline form in the usual sense, but appears under the microscope as separate round, slightly anisotropic masses of more or less uniform size.

If a small quantity of this powder be heated on a slide on a Lehmann's polarisation microscope[1] until it is completely fused, it will be found to be invisible on examination in the dark field between crossed nicols. On allowing the slide to cool somewhat, the isotropic substance undergoes a change, and a shower of anisotropic needle-shaped crystals suddenly appears on the dark background. This appearance is caused by the formation of liquid crystals. On further heating, this liquid crystalline phase is transformed into the isotropic state. Phrenosin exists in this intermediate fluid crystalline state not only when the dry powder is heated, but also when it is allowed to separate from its hot solutions in various solvents.

Though phrenosin, as usually obtained, exists in the amorphous state, true crystals were obtained from cerebron [= phrenosin] by Wörner and Thierfelder [1900]. They found that when cerebron was kept at 50° suspended in 85 per cent. alcohol, or at 60° in methyl alcohol-chloroform [Loening and Thierfelder, 1910], the amorphous so-called "crystalline" product was gradually transformed into true crystals. Thierfelder did not realise the nature of this change, and assumed that it depended on intramolecular variations. This phenomenon, which Wörner and Thierfelder [1900] designated "umlagerung," was satisfactorily explained by Rosenheim [1914, 1], who showed that it consisted in the gradual change of the solidified liquid crystalline modification into the true crystalline condition at the temperature favourable for its formation.

Since the ordinary amorphous form of phrenosin consists of solidified liquid crystals, Rosenheim attempted to prevent the formation of this phase and so favour the deposition of true crystals. This can best be accomplished by allowing a hot 2 per cent. solution of phrenosin in 85 per cent. alcohol to cool very gradually in an unsilvered Dewar flask. When the flask is put into a water-bath at 75° and the temperature of the water-bath allowed to fall, the first crystals appear when the temperature reaches 65°, while at 61° the flask is filled with a mass of glittering crystals. Under the microscope these crystals

[1] A suitable electric hot stage has been described by Lorrain Smith and Mair [1910, 2].

appear as transparent well-defined plates resembling cholesterol. Crystallised phrenosin obtained from dilute alcohol contains 1 molecule of water of crystallisation, which is not given up on drying *in vacuo* over concentrated sulphuric acid, but is removed on heating the substance at 105° [Rosenheim, 1914, 1].

Myelin Forms of Phrenosin.

In the presence of water phrenosin tends to give rise to myelin forms. The myelin forms of pure phrenosin were first observed in a preparation of Rosenheim's which was examined in Aschoff's laboratory [Kawamura, 1911]. Lorrain Smith and Mair [1910, 1] also observed that cerebrosides prepared by their method gave rise to similar formations. This phenomenon is intimately connected with the liquid crystalline condition, and is well seen when phrenosin is warmed with water on a slide under the microscope. Soon the small round masses swell up and are found to be covered with spicules which gradually develop into myelin forms. This takes place at a comparatively low temperature, and if the slide is allowed to cool it will be found that the phrenosin powder has taken up water and now appears as transparent globules. Under the polarising microscope the globules are strongly anisotropic and show the black cross of spherocrystals. With the selenite plate they behave exactly like the spherocrystals of phrenosin obtained from pyridine solution [Rosenheim, 1914, 1916].

Relation of above Phenomena to "Melting-point" of Phrenosin.

The melting-points recorded in the literature for phrenosin show variations from about 170° [Parcus, 1881] to 212° [Wörner and Thierfelder, 1900]. Thierfelder's cerebron became moist at 130°, slightly yellowish at 200°, and fused at 209° on slow heating and at 212° on rapid heating. Similar variations were found by Rosenheim [1914, 1] who observes that it is possible by slight changes in the conditions to obtain what appears to be a melting-point at any temperature between 170° and 215°.

This behaviour is explained by the fact that phrenosin exists in the liquid crystalline condition between the temperatures of 95° and 215° approximately. The different statements as to the melting-point of phrenosin are apparently dependent on the fact that some observers considered the substance as fused during the liquid crystalline phase,

while others took the higher temperature of the isotropic liquid phase as the melting-point.

There is really no true melting-point in the case of phrenosin, and the point at which it passes from the more viscid anisotropic liquid crystalline phase to the less viscid isotropic melt or liquid amorphous condition should not be termed its melting-point but its "clearing-" point [Lorrain Smith and Mair, 1910, 1; Rosenheim, 1914; Lapworth, 1913].

Optical Activity of Phrenosin.

Phrenosin is dextro-rotatory, the degree of its rotation being greatly influenced by the concentration, temperature and nature of the solvent. For investigations at ordinary temperatures pyridine is the most convenient solvent. "A 10 per cent. solution of phrenosin in pyridine, however, possesses at 20° only about half the optical activity of a 5 per cent. solution in chloroform-methyl alcohol at 40°, whilst a 10 per cent. solution in the latter solvent at 45° shows nearly three times the optical activity of a 10 per cent. pyridine solution at 20°" [Rosenheim, 1916]. It is therefore most important in recording observations on the optical activity of phrenosin that all the different factors should be stated.

As will be seen from the table, the results obtained by different observers agree fairly well with each other.

Observer.	Solvent.	Concentration. Per Cent.	Temperature.	Specific Rotation Obtained.
Kitagawa and Thierfelder [1906] .	Chloroform-methyl alcohol (3 : 1) .	5	50°	$[\alpha]_D^{50°} = +\ 6{\cdot}4°$ to $+\ 8{\cdot}4°$
Thierfelder [1914, 2] .	Chloroform-methyl alcohol (3 : 1) .	5	50°	$[\alpha]_D^{50°} = +\ 7{\cdot}4°$
Levene [1913, 1] .	Chloroform-methyl alcohol (3 : 1) .	6	—	$\alpha(D) = +\ 9{\cdot}5°$ to $+\ 10{\cdot}7°$
Rosenheim [1916] .	Chloroform-methyl alcohol (3 : 1) .	10	45°	$[\alpha]_D^{45°} = +\ 10{\cdot}4°$
,, . ,, .	Chloroform-methyl alcohol (3 : 1) .	5	40°	$[\alpha]_D^{40°} = +\ 7{\cdot}40°$
Levene [1913, 1] .	Pyridine . .	—	—	$[\alpha]_D = +\ 3{\cdot}05°$ to $+4{\cdot}14°$
Rosenheim [1916] .	,, . .	10	20°	$[\alpha]_D^{20°} = +\ 3{\cdot}78°$
,, ,, .	,, . .	10	20°	$[\alpha]_D^{20°} = +\ 3{\cdot}70°$
,, ,, .	,, . .	10	18°	$[\alpha]_D^{18°} = +\ 3{\cdot}70°$
,, ,, .	,, . .	10	30°	$[\alpha]_D^{30°} = +\ 4{\cdot}30°$

KERASIN.

Kerasin was the name applied by Thudichum [1874] to a second galactolipin which he succeeded in isolating from brain. A similar product was prepared by Parcus [1881] which he called *homocerebrin.* Following Thudichum, the term kerasin is now employed by common consent to indicate the second of the two galactolipins present in brain. A substance of the nature of kerasin was investigated by Kossel and Freytag [1893].

Kerasin very closely resembles phrenosin in its composition and physical properties, and furnishes very similar figures on elementary analysis, so that much in the description of phrenosin applies also to kerasin. It differs from phrenosin in certain physical properties. Thus while phrenosin is deposited from hot solutions in alcohol and in other solvents in the form of rosettes, kerasin separates in a characteristic gelatinous form. On microscopic examination, this jelly-like mass is found to consist of balls composed of very fine long radiating needles. This gelatinous state is apparently due to the very long silky needles enclosing large amounts of solvent.

When kerasin is crystallised from absolute alcohol in a flask and allowed to dry slowly after the alcohol has been poured off, it becomes white and easily pulverised, so that it crumbles off the sides of the glass. When deposited from solvents containing water it becomes, on drying, hard and waxy and difficult to powder.

Kerasin is only slowly deposited from its hot alcoholic solution, and if its amount does not exceed 1 part in 321 parts of alcohol, it is not deposited at all above 28°, and below that temperature only very gradually [Thudichum, 1884]. It behaves somewhat similarly towards acetone and towards various other solvents and mixtures of solvents [Rosenheim, 1916]. The only successful method for its isolation in approximately pure form is based on this property.

Thudichum's Isolation of Kerasin.

The " white matter " obtained from brain in the manner already described (p. 96) was extracted with ether, dried, powdered and dissolved in hot absolute alcohol. An insoluble residue remained from which the hot alcohol was decanted. On standing, a deposit began to form which was filtered off after the first hour, while a further deposit was separated after the second hour. Next day the filtrate contained a gelatinous body which was separated. The solution was

then allowed to stand for a few days in stoppered bottles, when a gelatinous membranous mass, mainly consisting of kerasin, was deposited. A further kerasin fraction was obtained from the filtrate by treatment with cadmium chloride, which removed the sphingomyelin present. The kerasin was further purified by recrystallisation three times from boiling absolute alcohol; at this stage the alcoholic solution gave no precipitate with cadmium chloride or platinum chloride, so Thudichum considered that it was free from sphingomyelin; phrenosin, however, was still present.

The product was again recrystallised from pure absolute alcohol, and on examining the precipitate after three hours by the aid of the microscope it was found to consist of wavy crystallised masses of kerasin, while no rosettes of phrenosin were visible. At this stage the crystals were isolated, again recrystallised from alcohol and dried *in vacuo*.

The kerasin prepared in this way always contained small amounts of phosphorus (sphingomyelin?), the lowest phosphorus percentage found being 0·08 per cent. Very appreciable amounts of phrenosin were also present in all Thudichum's preparations. In spite of this, his investigations on kerasin were attended with a considerable amount of success.

The Composition of Kerasin.

On analysis kerasin prepared in the above manner furnished the following data from which Thudichum calculated the empirical formula of kerasin to be $C_{42}H_{85}NO_8$ or $C_{44}H_{89}NO_8$. The figures were obtained from different samples:—

No.	C.	H.	N.	O.
1	69·54	11·69	1·92	16·85
2	69·01	11·44	1·90	17·65
3	68·44	11·39	1·73	18·42
Average	68·99	11·50	1·85	17·64

It is interesting to note that these results obtained from a highly impure product agree very well with analyses of much purer specimens of kerasin, and do not differ materially from the theoretical numbers calculated for this product, namely, C = 69·14, H = 11·49, N = 1·72 [Rosenheim, 1916].

This observation furnishes a good instance of the unreliability of analytical results as an index of purity in the case of the galactolipins. The difference in elementary composition between kerasin ($C_{47}H_{91}NO_8$) and phrenosin ($C_{48}H_{93}NO_9$) is so small that elementary analysis gives little or no indication of the presence of even a large amount of phrenosin in a kerasin fraction. Thus Thierfelder [1913] obtained a kerasin-like substance which gave almost theoretical analytical figures, and yet this kerasin contained such a large amount of phrenosin that on hydrolysis the fatty acid of phrenosin constituted 25 per cent. of the total fatty acids. So close is the resemblance between kerasin and phrenosin that Levene and Jacobs [1912, 2] originally considered them as optical isomers.

As the result of his experiments on kerasin, Thudichum concluded that kerasin, like phrenosin, was a *cerebroside*, which contained the sugar *cerebrose* combined with at least two other radicles. Of these, one was probably sphingosine, while the other was a fatty acid the nature and composition of which had not been perfectly ascertained. Later research has abundantly substantiated these statements of Thudichum, though it must be admitted that the experimental evidence on which they are based is much less complete than is generally found to be the case in the work of this investigator.

In extension of Thudichum's observations, Thierfelder [1913] showed that kerasin was made up of 1 molecule of galactose,[1] 1 molecule of sphingosine, and 1 molecule of an acid with the empirical formula $C_{24}H_{48}O_2$ which he called kerasinic acid. These results have been confirmed by Rosenheim [1916]. The only difference therefore between the constituents of kerasin and phrenosin lies in the fatty acid radicle.

Levene [1913] pointed out that Thierfelder's kerasinic acid was the same as lignoceric acid previously described by Hell and Hermanns [1880]. The nature of this acid has been already referred to and its relation to phrenosinic acid indicated: the fact that phrenosinic acid readily yields lignoceric acid on mild oxidation, throws an interesting light on the close connexion between the acids of the two galactolipins. Of the structure of the carbon chain of lignoceric acid ($C_{23}H_{47}COOH$) little is known except that it is branched. On recrystallisation from a mixture of light petroleum and acetone, lignoceric acid is obtained

[1] The galactose was not definitely identified until Rosenheim [1916] prepared the characteristic methylphenyl-hydrazone and showed that on oxidation mucic acid was produced.

in silky white crystals forming a loose powder which assumes a wax-like consistency when compressed in an agate mortar [Rosenheim, 1916]. Unlike phrenosinic acid, this acid is optically inactive.

Constitution of Kerasin.

The chief points on which the tentative constitution of kerasin is based are the same as those already discussed under phrenosin. It is assumed that kerasin is a glucoside [Rosenheim, 1913].

Kerasin when dried *in vacuo* at ordinary temperatures has the empirical formula $C_{47}H_{91}NO_8 + H_2O$ [Rosenheim, 1916]. On heating to 105° it gives up water. For samples of the purest kerasin hitherto isolated Rosenheim [1916] obtained the following figures :—

No.	1.	2.	3.	4.	5	Average.	Calculated for $C_{47}H_{91}NO_8H_2O$.
C	68·91	68·98	68·95	68·98	68·90	68·94	69·14
H	11·44	11·65	11·23	11·21	11·46	11·39	11·49
O	1·83	—	1·74	1·86	1·76	1·79	1·72

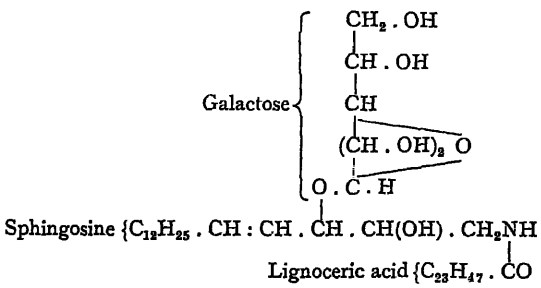
With the exception that kerasin forms a penta-acetyl derivative [Thierfelder, 1914] instead of the hexa-acetyl compound furnished by phrenosin the chemical reactions of the two substances are very similar. Thus kerasin furnishes no nitrogen when treated with nitrous acid [Rosenheim, 1916; Levene and Jacobs, 1912, 2] and has neither an acid nor alkaline reaction [Thierfelder, 1914, 1]. On hydrolysis with mineral acids in aqueous solution, it furnishes galactose, lignoceric acid and a salt of sphingosine, while during methyl alcohol hydrolysis monomethyl sphingosine and the methyl ester of lignoceric acid are formed [Rosenheim, 1916]. Kerasin also forms a penta-methyl derivative when methylated by Irvine's method [Pryde and Humphreys, 1924].

From these results it is obvious :—

1. That in kerasin one hydroxyl group of sphingosine is free.[1]
2. That kerasin contains five hydroxyl groups.
3. That the combination of sphingosine with fatty acid is through the amino and carboxyl groups as in phrenosin.

From consideration of these points, Rosenheim [1916] proposed the following constitutional formula for kerasin :—

[1] The evidence as to the formation of monomethyl sphingosine during methyl alcohol hydrolysis is still inconclusive; it is to be hoped that this will be definitely settled shortly, for its bearing on the possible structure of phrenosin is obviously important.



This formula is of course only put forward as a probable one, which may be either confirmed or shown to be untenable by future research. The possibility, in the case of both galactolipins, of a linkage of sphingosine with galactose through the amino group must not be overlooked. It does not appear that the synthetic carbohydrate esters of the higher acids obtained by Bloor [1912, 1912, 1] have any bearing on the structure of the galactolipins.

Physical Properties of Kerasin.

In general physical properties, such as the formation of liquid crystals and myelin forms, kerasin is similar to phrenosin. Kerasin exists in the liquid crystalline state at temperatures from below 100° up to 180°, and like phrenosin it shows a "clearing"-point instead of a melting-point—i.e. a point at which the anisotropic liquid crystalline phase passes into the liquid amorphous melt. Though true crystals of phrenosin can be obtained under certain conditions, as already described, true kerasin crystals have not yet been observed.

Optical Activity of Kerasin.

Thierfelder [1913] stated that a kerasin fraction obtained by him was inactive, and a similar observation was made by Levene and Jacobs [1912, 2]. These statements were due to the fact that the material used by the above investigators contained phrenosin. Many years ago Rosenheim and Tebb [1907] showed that kerasin was optically active and differed from phrenosin in that it was lævo-rotatory. Some of the latest figures obtained from the most highly purified specimens of kerasin hitherto examined are as follows: [Rosenheim, 1916]. The observations were carried out in a tube 1 decimetre long. As in the case of phrenosin, the degree of optical activity varies with the temperature, concentration and nature of the solvent.

No.	Solvent.	Concentration.	Temperature.	Specific Rotation Obtained.
1	Pyridine	Approx. 10 per cent.	20°	$[\alpha]_D^{20°} = -2·74$
2	,, ...	,, ,, ,,	18°	$[\alpha]_D^{18°} = -2·78$
3	,, ...	10 per cent.	18°	$[\alpha]_D^{18°} = -2·50$
4	,, ...	Approx. 10 per cent.	25°	$[\alpha]_D^{25°} = -3·71$
5	Chloroform and pyridine	10 per cent. ,, ,, ,,	50°	$[\alpha]_D^{50°} = -5·08$
6	Pyridine	,, ,, ,,	25°	$[\alpha]_D^{25°} = -3·78$
7	Pyridine and acetone (1 : 1) .	,, 5 ,,	50°	$[\alpha]_D^{50°} = -4·58$

Preparation of the Galactolipins.

In the preparation of the galactolipins the two main points to be considered are :—

1. The separation of the galactolipins from accompanying phospholipins and cholesterol.

2. The separation of the purified galactolipin mixture into its components—phrenosin and kerasin.

For the preparation of the galactolipins the best material is brain. The means adopted for the separation of the galactolipins from the other brain lipins may be divided into two groups. In the older methods generally, phospholipins were separated from galactolipins by purely physical means, chiefly by the use of alcohol [Thudichum, 1884], glacial acetic acid [Koch, 1904], and other solvents or mixtures of solvents. Since the removal of certain phospholipins was accomplished by this method only with the greatest difficulty and sometimes very imperfectly, certain observers took advantage of the relative resistance of galactolipins to saponification. They boiled the mixture with baryta for a short time, and thus destroyed the phospholipins while the galactolipins were left intact. The resulting hydrolytic mixture contained the degradation products of the phospholipins together with the galactolipins, which were now more easily separated in the pure state.

In the baryta method the brain itself was sometimes boiled with the baryta [Müller, 1858; Parcus, 1881], and the galactolipins subsequently extracted, while in other cases the deposit obtained on cooling an alcoholic extract of brain was employed. This method, which was originally introduced by Müller [1858], has been used, with certain slight modifications, by many recent observers: Kossel and

Freytag [1893]; Loening and Thierfelder [1911]; Smith and Mair [1910; 1911; 1913, 1]; Fränkel [1911]; Lapworth [1913].

There can be no question that preliminary treatment with baryta materially facilitates the isolation of the mixture of galactolipins, and the only possible argument against its use is the fact that the galactolipins themselves are not entirely resistant to the prolonged action of aqueous or alcoholic baryta solutions. This does not appear to be of much importance from the practical standpoint, for prolonged boiling is not required, and Loening and Thierfelder [1911, 1912] showed that galactolipins were apparently not injured by boiling for short periods with baryta, or even with methyl alcohol solutions of potassium hydroxide. On the other hand, too prolonged boiling might possibly give rise to difficulties, and in this connexion it is perhaps significant that only those observers who used the baryta method found a high nitrogen percentage in their products. This fact suggests that their preparations contained certain amounts of the nitrogenous base sphingosine derived from sphingomyelin, or perhaps from the galactolipins themselves [Rosenheim, 1914].

Even with the help of baryta, great difficulties are experienced in the isolation of phosphorus-free galactolipins, chiefly due to the fact that alcohol, which was universally used for recrystallisation, is unsuitable. This difficulty was to a great extent overcome by Lorrain Smith and Mair [1910] and by Loening and Thierfelder [1911], who, working independently, replaced alcohol by acetone. By this modification it is easy to obtain pure galactolipins from brain, but in all cases the product obtained is a mixture of the two galactolipins—phrenosin and kerasin.

Subsequently an improvement in the methods of isolating the galactolipins was introduced by Rosenheim [1914], who extracted these substances directly from the brain by means of pyridine. The mixture so obtained is separated into its constituents by temperature fractionation from pure acetone.

Observations on the Separation of Phrenosin and Kerasin.

The separation of these two bodies from each other is a troublesome matter, the chief causes of the difficulty being dependent on the following points [Rosenheim, 1914]:—

1. The close resemblance in their chemical constitution.
2. The close resemblance of their physical properties—solubility, etc.

3. Their chemical inertness, which prevents the formation of derivatives suitable for their purification.
4. The fact that they form liquid crystals, which, according to O. Lehmann, are easily and readily miscible.
5. The absence of any criterion of purity by which the completeness of the separation can be judged. Elementary analysis and melting-point determinations are of no value in this respect, and, indeed, may even prove misleading.

The actual isolation of phrenosin and kerasin from a mixture of these two substances can be accomplished by the method of temperature fractionation from alcohol introduced by Thudichum [1884], or by a modification of this method in which acetone is used [Rosenheim, 1914]. No method except that of fractionation, as suggested by Thudichum, has proved of any value in the separation of these products.

For indicating the progress of the separation of the galactolipin mixture, two observations made by Rosenheim and Tebb [1908] are of considerable value:—

1. Phrenosin in pyridine solution is dextro-rotatory, while kerasin is lævo-rotatory in the same solvent.

2. The behaviour of the two substances under the polarising microscope is characteristically different. This fact permits of the detection of phrenosin in presence of kerasin, and *vice versa*, by a simple test known as the selenite-plate test.

Selenite-Plate Test [Rosenheim, 1914].

On gradually cooling a warm 10 per cent. solution of phrenosin and kerasin, both these products separate in the form of sphero-crystals. If these crystals are now examined by means of a polarisation microscope with crossed nicols, and if a selenite plate is placed below the stage and immediately above the polariser in such a way that its axis lies diagonally to the plane of polarisation of the crossed nicols, a characteristic difference between phrenosin and kerasin is at once seen. The sphero-crystals now appear to be divided into quadrants of which the opposite ones show the addition colour blue, whilst the two others show the subtraction colour yellow. The important point is that while the sphero-crystals of phrenosin show the blue colour in the upper right and left lower quadrants, the sphero-crystals of kerasin show the blue colour in the reverse positions—in the left

upper and right lower quadrants. By means of this simple physical test, it is possible to indicate in a very small amount of material when a pure sample of phrenosin or kerasin has been obtained. That the test is sufficiently sensitive for practical purposes follows from the fact that a kerasin fraction which was found to be free from phrenosin by this test gave on hydrolysis no trace of phrenosinic acid, the typical fatty acid of phrenosin.

The general principles involved in the isolation of cerebrosides will be seen from the description given below of the two chief methods now in use—(1) the baryta method in combination with acetone as used by Thierfelder, and (2) Rosenheim's pyridine method. The direct extraction and isolation by means of alcohol as employed by Thudichum has been already described.

I. Isolation of Galactolipins by Baryta and Acetone Method.

Loening and Thierfelder [1911] obtained galactolipins from brain in the following manner: The brain was dried and treated with ether. The residue was then extracted with alcohol at 45°, and the precipitate (" protagon ") obtained on cooling used for the preparation of galactolipins. A known weight of this protagon was rubbed up with saturated baryta water, the mixture placed in a flask, mixed with six times its volume of this fluid and heated on a boiling water-bath for one to two hours. The flask now contained a precipitate and a clear yellowish supernatant fluid. The precipitate was separated by means of the suction pump, washed with water to remove traces of barium, and finally with cold acetone to remove water. It was then extracted many times with boiling acetone; in the first extraction, boiling was continued for a few minutes only, but in the later ones for several hours. From the first acetone filtrate a well-marked precipitate deposited on cooling: the amount of precipitate from subsequent extracts gradually became less and less, until in the case of the final extracts nothing separated unless the mixture was cooled in ice water, and, even then, only traces were obtained. The whole of the galactolipins, however, could not be extracted by this method, even after boiling with acetone for from eight to twelve hours, but the final extract contained so little that it hardly influenced the yield when the method was used quantitatively. The precipitates, with the exception of the first, which was slightly coloured, were pure white. All the different precipitates were mixed, dried and weighed. The

mixture was found to be entirely free from phosphorus and barium. Separation of the two components of this galactolipin mixture was brought about by the employment of Thudichum's temperature fractionation method.

An excellent description of a similar method for isolating galactolipins is given by Lorrain Smith and Mair [1910; 1913, 1], who worked out and used this method before Thierfelder's publication appeared.

II. Isolation of Galactolipins by Rosenheim's Pyridine Method.

The method consists in the employment of the various steps indicated below. The crude galactolipins are first separated and the mixture afterwards divided into its constituents.

A.

Preparation of Crude Galactolipin Mixture [Rosenheim, 1913].

1. *Treatment of Brain with Acetone.*

The finely minced ox brain was suspended in acetone and allowed to stand, with frequent stirrings, for twenty-four hours at room temperature. The watery acetone extract was decanted, and the brain pulp strained through several layers of fine muslin. At least six subsequent extractions with acetone were made, until the last extract yielded on evaporation only an inappreciable amount of cholesterol.

The tissue was next spread in a thin layer on a large glass plate, gently warmed from below, and freed from acetone by means of an air current generated by an electric fan. The brain tissue was now practically free from water and cholesterol, and much fat and fatty acids were removed.

2. *Cold Petroleum Ether Treatment.*

The somewhat waxy powder was extracted with cold petroleum ether to remove the unsaturated phospholipins (lecithin, kephalin, and their decomposition products). The residue, freed from petroleum ether in the manner described above, was passed through an Excelsior mill, whereby a fine cream-coloured powder was obtained.

3. *Isolation of Crude Galactolipins by Pyridine.*

This powder was treated with pyridine and the mixture warmed to 45° to allow the solvent to penetrate the tissues; it was then rapidly cooled to room temperature and filtered by means of a Buchner funnel. From the pyridine filtrate, the galactolipins were obtained by pouring it into three to four volumes of acetone, when a bulky precipitate at once formed. In order to increase the yield the pyridine-acetone mixture was cooled to 0°, and the precipitate separated by filtration through a plain filter paper. It was then thoroughly washed with acetone, removed from the filter paper and suspended in excess of acetone. Finally, the product was extracted with ether in a Soxhlet apparatus to remove the last traces of ether-soluble phospholipins.

The crude galactolipins thus obtained presented a slightly yellowish appearance, but after being twice recrystallised from 15 volumes of an alcohol-chloroform mixture (1 : 2) were pure white. The substance contained 1·68 per cent. of nitrogen, and was almost phosphorus-free, containing only ·08 per cent.

B.

Separation of Phrenosin and Kerasin from Crude Galactolipin Mixture [Rosenheim, 1914].

Rough Separation by Acetone into Two Fractions.

The finely powdered galactolipin mixture was treated with excess of acetone containing 10 per cent. of water, on a water-bath kept at 56°. About 85 per cent. of the product went into solution. The clear acetone solution was allowed to cool in an incubator at 37°. After sixteen to twenty hours a crystalline deposit had formed from which the supernatant fluid was decanted through a filter warmed to 37°. This crystalline deposit consisted chiefly of phrenosin, and is referred to later as the *phrenosin fraction.*

On allowing the filtrate to stand in an ice-chest for twenty-four hours or longer, a milky gelatinous precipitate was obtained which was chiefly kerasin and is considered as the *kerasin fraction.*

The precipitates were filtered under pressure, washed with acetone and dried *in vacuo.*

Phrenosin.

(1) *Isolation of phrenosin from phrenosin fraction by glacial acetic acid-chloroform mixture* (3 : 2).

The phrenosin fraction was dissolved in four volumes of chloroform at about 60°, and to the solution were added six volumes of glacial acetic acid previously warmed to the same temperature. The clear solution was kept in an incubator at 37° over night, the deposit filtered and washed at 37° with acetic acid-chloroform mixture.

The moist precipitate was again dissolved in the mixture and the solution heated as before. The mother liquors, from these two recrystallisations, deposited at room temperature a considerable amount of gelatinous precipitate, which was worked up with the kerasin fraction.

The product obtained at 37° was granular and easy to filter. When recrystallised a third time in this way, the mother liquor no longer gave a deposit on cooling to room temperature.

On examination by the selenite plate only a small quantity of kerasin was found to be present at this stage. The product was entirely free from phosphorus.

Since no further separation of kerasin could be accomplished by means of the acetic acid-chloroform mixture, another solvent, acetone-chloroform was used.

(2) *Further purification of nearly pure phrenosin with acetone-chloroform mixture* (3 : 2).

The product was dissolved in four volumes of chloroform and six volumes of warm acetone added. The granular deposit which formed was filtered at 37° and twice more recrystallised in the same way. The substance now obtained appeared to be perfectly uniform, since no indication of the presence of kerasin was obtained on examination by the selenite plate. Finally, the phrenosin was recrystallised from a large volume of acetone containing 10 per cent. of water. The product obtained in this way appeared to consist of pure phrenosin.

Kerasin.

(1) *Isolation of kerasin from kerasin fraction of glacial acetic acid-chloroform mixture* (3 : 2).

The kerasin fraction described above was dissolved in four volumes of chloroform at 50°, and to the solution were added six volumes of

glacial acetic acid previously warmed to about 60°. When kept at 37° a granular white layer mainly consisting of phrenosin collected on the surface and was filtered off. The filtrate began to deposit on cooling to 26°, and solidified finally to a gelatinous mass. After filtering and washing with the acetic acid-chloroform mixture the product was suspended in acetone. On filtration it was again recrystallised from acetic acid-chloroform mixture as before. A small amount separated at 37°, but the main quantity deposited at room temperature. The process was repeated twice more, when it was found that the solution no longer furnished a deposit at 37°, even when kept at that temperature for many hours. At this stage the selenite plate showed that the substance consisted almost entirely of kerasin.

(2) *Further purification of nearly pure kerasin by acetone-pyridine mixture* (1 : 1).

The product was dissolved in 10 volumes of pyridine to which 10 volumes of acetone warmed to 45° were added. On cooling to 37° in the incubator only a faint cloud of phrenosin appeared. The filtrate began to deposit at 28°, and was allowed to cool to room temperature before filtration. This process was repeated, and the product finally recrystallised from a large volume of 90 per cent. acetone containing 2 per cent. pyridine. The kerasin so obtained appeared to be pure.

Occurrence of Galactolipins in the Different Organs and Tissues.

Though brain and also nerve material [Chevalier, 1886] constitute the chief sources of the galactolipins, products identical with, or similar to, the galactolipins have been isolated from many other organs and tissues. It is not improbable that all adult animal organs contain at least traces of these substances, and their presence must be assumed in all organs yielding so-called protagon. The presence of galactolipins has been established with more or less certainty in kidneys [Dunham, 1905; Rosenheim and MacLean, 1915]; heart [MacLean, 1913]; retina [Cahn, 1881]; thymus [Lilienfeld, 1893]; adrenals [Rosenheim and Tebb, 1909, 2]; liver [Waldvogel and Tintemann, 1904]; egg-yolk [Stern and Thierfelder, 1907]; red blood corpuscles [Bang and Forsmann, 1906]; pus [Hoppe-Seyler, 1871; Kossel and Freytag, 1893]; adipocere and spermatozoa [Kossel and Freytag,

1893] ; sputum [Schmidt and Müller, 1898] ; mushrooms [Bamberger and Landsiedl, 1905 ; Zellner, 1911], and other tissues.

It is interesting to note that galactolipins appear to be absent in the brain of the fish [Argiris, 1908]. The distribution of galactolipins in the developing brain is described by Lorrain Smith and Mair [1912, 1913].

Galactolipins other than Phrenosin and Kerasin.

It has been generally accepted that the individual galactolipins described by different observers under various names consisted essentially of more or less pure phrenosin or kerasin. The relationship of these differently named substances to each other has been the subject of discussion by such observers as Thierfelder [1904], Posner and Gies [1905], Fränkel [1909], Bang [1911], Cramer [1911], Levene and Jacobs [1912, 2], Rosenheim [1916], and others.

From the evidence available there seems little room for doubt that these bodies consist mainly of Thudichum's phrenosin or kerasin in a more or less pure state as shown in the following list:—

Phrenosin	Cerebrin [Müller, 1858 ; Koch, 1902, and others].
	d-Cerebrin [Levene and Jacobs, 1912, 2].
	Pseudocerebrin [Gamgee, 1880].
	Cerebrone [Wörner and Thierfelder, 1900].
	Pyosin [Kossel and Freytag, 1893].
	Amino-cerebrinic acid glucoside [Bethe, 1902].
Kerasin	Homocerebrin [Parcus, 1881].
	Pyogenin [Kossel and Freytag, 1893].

Of the various substances isolated by Thudichum to which he gave the names æsthesin, psychosin, krinosin, breginin, cerebrinic acid and sphærocerebrin, some, such as æsthesin and psychosin, were undoubtedly decomposition products, and it is possible that all these bodies come under this category. Recently, however, evidence has been brought forward that a galactolipin containing an unsaturated fatty acid radicle is present both in human and ox brains, closely resembling kerasin in its properties. It seems probable, therefore, that a third galactolipin, for which Klenk has suggested the name Nervon, occurs in the brain and must have been contained in many samples of kerasin and phrenosin.

Nervon (Thierfelder and Klenk, 1925 ; Klenk, 1925).—In attempting to repeat Fränkel's and Kafka's work on the isolation of a diamino-

phospholipin from brain, Thierfelder and Klenk succeeded in isolating a galactolipin closely resembling kerasin but distinguished from it by the nature of the fatty acid radicle present. The brain tissue was extracted with petroleum ether, the kephalin precipitated by the addition of alcohol, the filtrate concentrated and the residue taken up in alcohol. To this solution a hot saturated alcoholic solution of lead acetate containing ammonia was added, and the precipitate decomposed by hydrogen sulphide in hot alcoholic solution. The precipitate, which formed in the filtered solution on standing, was treated with acetone containing 1 per cent. HCl, by which means any phospholipin present was dissolved. After further purification a substance, free from phosphorus, was obtained which gave on hydrolysis sphingosine, galactose and an unsaturated fatty acid of the oleic series $C_{24}H_{46}O_2$ melting at 40·3°, and having an iodine value of 68. It is interesting that Grey (1913) isolated from brain a solid unsaturated fatty acid melting at 42°. Klenk (1926) reduced the unsaturated acid and obtained the normal tetracosanic acid melting at 85° identical with normal tetracosanic acid synthesised by Brigl.

Quantitative Estimation of Galactolipins.

The earlier attempts at the quantitative estimation of the galactolipins in brain were generally carried out by the method introduced by Noll [1899], in which the " protagon " from brain was hydrolysed, and the amount of reducing sugar so obtained estimated by Fehling's solution [Koch, 1904]. The yield of sugar afforded some clue to the amount of galactolipins present, but the method did not give very satisfactory results. Falk [1908] attempted to separate the galactolipins and weigh them as such, but without much success. In more recent times Lorrain Smith and Mair [1911; 1913, 1] have carried out some careful quantitative estimations, which no doubt yielded the first reliable results we possess. These observers separated the galactolipins from other lipins with baryta and weighed them directly. From their figures it appears that the percentage of galactolipins in normal human brain is about 1·6 per cent. in wet and 7·3 per cent. in dried brain.

Rosenheim [1916] isolated galactolipins by the method described above and obtained 2 per cent. for wet brain and 9 per cent. for dry brain. These figures, which were obtained by weighing a crude product, agree fairly well with those of Lorrain Smith and Mair.

CHAPTER V.

ALLEGED LIPINS.

(1) PROTAGON.

In describing sphingomyelin it was stated that this phospholipin is obtained in the crude state when brain or other animal tissue is extracted with hot alcohol. On cooling the alcoholic extract, a whitish precipitate forms, which contains sphingomyelin and galactolipins along with small amounts of other substances. To the part of this crude precipitate which remained after extraction with ether Liebreich [1865] gave the name protagon. Protagon " is nothing more than the solid part of an alcoholic extract of the brain, the more soluble portions of which solid part have been washed away with ether " [Thudichum, 1896]. For the last fifty years the name " protagon " has from time to time appeared, particularly in connexion with investigations on brain chemistry, but from the nature of the subject only a comparatively small number of chemists have taken any interest in it, and to many the name may have appeared unintelligible. To some, according to Thudichum, " it was so much so that they believed it to be that of an animal." This substance, however, has given rise to more bitter and acrimonious discussion among certain investigators than any other of the lipin bodies, and much energy has been expended by different observers in endeavours to ascertain whether protagon is a chemical unit or a mixture.

The question after all does not appear to be of supreme importance, but to the various " Protagonists," who have from time to time come forth in support of their contentions, it seemed to be a point of material moment.

Nature of Protagon.

Protagon is a white non-hygroscopic product which separates from solvents in the form of more or less well-defined crystals; when a warm alcoholic solution of protagon is quickly cooled beautiful rosettes and needles are obtained. After drying *in vacuo* it forms a light white powder. Protagon is practically insoluble at room temperature in

the majority of the ordinary organic solvents, but dissolves in warm pyridine, methyl alcohol, ethyl alcohol, glacial acetic acid, acetone and in various mixtures of solvents. On cooling these solutions, precipitation takes place: in cold or boiling ether, protagon is practically insoluble. The principal solvent used in investigations on protagon is alcohol: from hot or boiling alcohol in which the substance is easily soluble, deposition readily takes place on cooling, and this property is made use of extensively in the isolation of protagon.

Protagon which has been dried *in vacuo* is much less soluble in hot alcohol than moist (hydrated ?) protagon [Posner and Gies, 1905, 1]. A somewhat similar behaviour is exhibited towards other solvents such as hot acetone, in which protagon after drying becomes much less soluble than it was previously [Rosenheim and Tebb, 1909, 1]. This curious behaviour appears to be characteristic of certain lipin substances as pointed out by Bang and Forsmann [1906].

All investigators are now agreed that the chief constituents of protagon are—

1. Galactolipins (phrenosin and kerasin),
2. Sphingomyelin,

while small amounts of other substances are also present. The crystalline appearance of protagon, together with the fact that under given conditions the substance can be recrystallised from alcohol without any appreciable change in its composition, strongly suggests, at first sight, that the body is a definite chemical compound. This question is fully discussed below, and evidence advanced which must be accepted as proving definitely that protagon, despite the superficial characteristics mentioned, must be regarded as a mechanical mixture. This mixture is composed of the difficultly soluble galactolipins and sphingomyelin in such proportions that the product usually contains about 1 per cent. of phosphorus. Although the brain yields large amounts of protagon, it may also be obtained from many other organs. According to Thudichum [1879; 1880; 1880, 1], Rosenheim and Tebb [1909], and others, protagon always contains potassium; this, however, is denied by Gamgee [1880, 1][1] and Cramer [1911]. Sulphur is generally present, but it is not known in what form it exists; iron has also been found by some observers [Rosenheim and Tebb, 1909]. No purpose would be served in enumerating certain alleged physical constants of this mixture such as its melting-point. Some important

[1] Roscoe [1880; 1880, 1] states that he found 0·0236 per cent. of potassium in a sample of Gamgee's protagon.

optical phenomena exhibited by protagon and dependent on its sphingomyelin constituent will, however, be considered here.

The name protagon has entirely lost its original significance, but is useful in designating certain mixtures of galactolipins and sphingomyelin obtained from organs by extraction with hot alcohol and other solvents. For this purpose it is perhaps worth while retaining a name which has ceased to have any meaning in the chemical sense, but is of some importance from the practical point of view. The tremendous amount of literature which has sprung up in connexion with this substance also renders it advisable to retain the name protagon at least for the present, otherwise confusion might ensue.

Some Optical Phenomena Associated with Protagon.

Rosenheim and Tebb [1907] showed that protagon was optically active, an observation which was confirmed by Wilson and Cramer [1908]. When dissolved in pyridine in 3 per cent. solution and examined at 30° protagon possesses a slight dextro-rotation, which when expressed in terms of specific rotation amounts to about $[\alpha]_D^{30} = + 6{\cdot}8$. On raising the temperature this dextro-rotation decreases till at 50° optical inactivity results. The same phenomenon is observed when the temperature is allowed to fall below 30°. During cooling a slight haze is observed, due to partial deposition of the sphingomyelin of the dissolved product, and simultaneously with the formation of this deposit the fluid becomes strongly lævo-rotatory. This lævo-rotation finally reaches a maximum value which, when expressed as $[\alpha]_D$ is equal to $-$ 100° to $-$ 116°: the temperature at which this maximum result is observed is about 15° to 20°. At this stage observation is rendered difficult by the opacity of the fluid. As the precipitate settles the lævo-rotation gradually decreases, until after a period varying from a half hour to three hours a clear supernatant fluid shows a constant rotation of $[\alpha]_D = - 13{\cdot}3°$. On shaking the contents of the tube and thereby distributing the precipitate in the fluid, the remarkable fact is observed that the lævo-rotation reaches the high value of about $-$ 232°. On again heating the tube to 30° the original dextro-rotation of 6·8° is obtained [1] [Rosenheim and Tebb, 1908, 1].

[1] Rosenheim and Tebb have pointed out that the calculation of the observed rotation as $[\alpha]_D$ is not justified in the case of protagon because it is not a definite chemical compound, and also because the constituent to which its optical activity is principally due does not follow the laws of optical activity as expressed by Biot. A calculation of the results

In the course of an investigation into the cause of these curious changes Rosenheim and Tebb [1908, 3] succeeded in elucidating several important points bearing on the alleged unit nature of protagon, while at the same time a new physical phenomenon was discovered. These observers examined the precipitate formed on cooling a protagon solution as well as the supernatant fluid, and found that the precipitate consisted largely of impure sphingomyelin. Investigation of this phosphorus-rich deposit in the polarimeter proved that the peculiar behaviour of protagon in polarised light was mainly due to this constituent of protagon. When this sphingomyelin deposit was dissolved in pyridine and its optical activity investigated it was found to exhibit the same phenomena as protagon. The supernatant fluid, as already stated, showed in most cases an optical activity of $[\alpha]_D = -13{\cdot}3°$. After filtration the clear pyridine solution obtained was found to be inactive. When carefully pipetted off so that it appeared perfectly clear its optical activity was as before $[\alpha]_D = -13{\cdot}3°$. By filtration through paper it had lost its optical activity. From this it appeared that the lævo-rotation observed must have been due to a substance in suspension, an assumption which was proved to be correct by the observation that the lævo-rotatory clear fluid became inactive after centrifugalising.

We have here the first case described in the literature in which an optically active "solution" becomes inactive on centrifugalising owing to the removal of suspended particles. The explanation of this phenomenon was found in the peculiar physical structure of these particles, which Rosenheim and Tebb succeeded in demonstrating by means of the polarising microscope.

This Phenomenon is produced by "Fluid Sphero-crystals" of Sphingomyelin.

When the sphingomyelin precipitate, obtained by cooling a pyridine solution of protagon, is examined under the microscope in ordinary light it is seen to consist of small globules resembling fat globules, but owing to their transparency they are difficult to distinguish. Their spherical form is, however, well seen in dark illumination. Further examination of these globules between the crossed prisms

as $[\alpha]_D$ is, however, of value for comparative purposes. The exact figures obtained with different protagons vary somewhat, and depend on the phosphorus percentages of the products. The results quoted here were obtained with a protagon containing about 1 per cent. of phosphorus.

of a polarising microscope shows them to be strongly anisotropic, standing out brightly on a black background and being divided into quadrants by a black cross. These anisotropic sphero-crystals are apparently present in that state of matter which O. Lehmann [1904] designated as the " fluid crystalline phase." The rotation of the plane of polarised light by suspended particles as described above seems to be a property of fluid sphero-crystals, and Rosenheim and Tebb have called the phenomenon sphero-rotation. The galactolipins and sphingomyelin of protagon tend to form mixed liquid crystals, a fact which explains to a great extent the difficulties encountered in their separation.

Short Historical Account of Protagon.

Though the name protagon was first used in 1865, there is ample evidence that substances similar to this body had already been isolated by former observers. Liebreich [1865] obtained protagon by treating brain with water and ether; on standing for some time the ether formed a separate layer and was removed. This treatment with ether was repeated, and after removal by filtration of as much water and ether as possible, the residue was extracted with 85 per cent. alcohol at 45°. The extract was allowed to stand at 0°, when a precipitate formed. This precipitate was washed with ether, then moistened with water and purified by dissolving in alcohol at 45°. White crystals of protagon were thus obtained, their exact form being determined by the amount of alcohol used.

In spite of the fact that similar substances had previously been prepared and described by various investigators, this product of Liebreich for some obscure reason received a quite undue amount of attention. Consideration of the methods of preparation, and of the analytical data and properties of certain of these earlier bodies, leaves little doubt that the first substance of the nature of Liebreich's protagon was isolated by Fourcroy [1793], who obtained a " yellowish-white matter " in the form of glistening scales on extracting brain with boiling alcohol. Vauquelin's [1812] " white matter," Couerbe's [1834] " cerebrote," Fremy's [1841; 1841, 1, 2] " cerebric acid," Gobley's [1847, 1850] " cerebrin," Von Bibra's [1854] " cerebric acid," and products isolated by a few other investigators, were all of the same general nature as protagon. The " white matter " of Vauquelin differed in its method of preparation from protagon in that it had not been washed with ether, but Couerbe's " cerebrote " was at

least in some cases prepared by a method practically identical with that of Liebreich.

The similarity of these substances to protagon is shown in the figures representing their composition. With the exception of the phosphorus content the agreement is wonderfully close, especially when we consider that the methods of analysis at the disposal of the earlier observers were very unreliable.

	C.	H.	N.	P.	S.[1]
Couerbe's cerebrote [1834] . .	67·82	11·10	3·40	2·33	2·14
Fremy's cerebric acid [1841] . .	66·7	10·6	2·3	0·9	—
Gobley's cerebrin [1850] . .	66·85	10·82	2·29	0·43	—
Bibra's cerebric acid [1854] . .	66·78	10·65	2·51	0·52	—
Liebreich's protagon [1865] . .	66·74	11·74	2·80	1·23	—

Liebreich paid but little attention to any of these earlier results, and dismissed all previous substances similar to protagon as "decomposition products." The alleged important point in Liebreich's preparation of protagon was the employment of alcohol at 45° for extraction of the brain substance. He declared that alcohol at a higher temperature decomposed protagon, and since previous investigators had made use of boiling alcohol, it was obvious that their substances could not have been protagon, but a mixture of the products of protagon decomposition. Boiling alcohol, however, does not readily decompose protagon [Thudichum, 1896; Gamgee, 1880], and it still remains somewhat of a mystery why Liebreich gave yet another unnecessary name to a substance which had already received so much attention in this respect. Liebreich himself believed that his protagon constituted the mother substance of practically all phosphorised bodies hitherto described, such as lecithin and cerebric acid. Hoppe-Seyler [1866, 1], in whose laboratory Liebreich worked, at first supported this view, and so for a few years protagon was hailed as one of the few known important substances essential for the carrying on of the vital processes in all animal and vegetable cells [Fischer, 1865, 1868; Hermann, 1866; Tolmatscheff, 1867].

Very soon, however, evidence began to accumulate which cast doubts on the claim that lecithin and similar substances were derivatives of protagon. Parke [1867] showed that egg-yolk contained a phosphorised organic compound which was not protagon, while Hoppe-Seyler [1866, 1867] stated that egg-yolk and red blood corpuscles

[1] All contained sulphur probably.

both contained lecithin, but were entirely free from protagon. Since the methods used in these investigations could not have decomposed any hypothetical pre-existent protagon, it gradually became clear that protagon did not stand to lecithin in the relationship of "mother substance," as claimed by Liebreich. Similar conclusions were arrived at by Diaconow [1867; 1867, 1].

A further blow was dealt at this product by Diaconow [1868], who claimed to have obtained evidence that brain protagon was not a chemical unit. He considered that protagon consisted of a mixture of lecithin and some phosphorus-free fatty matter similar to a substance (cerebrin) isolated by Müller [1858]. Diaconow's results also strongly supported the view that lecithin existed preformed in the brain.

It is interesting to note that both Liebreich and Diaconow were pupils of Hoppe-Seyler and obtained their divergent results while working in the same laboratory. Though Hoppe-Seyler at first appeared to accept Liebreich's conclusions as to protagon without reserve, the results of Diaconow and other investigators, coupled with his own observations on red blood corpuscles, caused him to modify his previous views. Diaconow's contention that protagon was a mixture now received the weighty support of Hoppe-Seyler, and various publications from his laboratory supported this view [Jüdell, 1869; Hoppe-Seyler, 1869, 1871; Miescher, 1871].

Thudichum [1874], working independently, arrived at similar conclusions as to the non-unit nature of protagon, but did not agree with Diaconow that it consisted of lecithin and cerebrin. According to Thudichum, protagon was a mixture of cerebrin, phrenosin, kerasin and similar products, together with myelin, kephalin and cholesterin. The view that protagon was a mixture was also supported by Petrowsky [1873], Bourgoin [1874] and by Gorup Besanez [1878].

In the light of all this evidence, there was at this period a general agreement among physiological chemists that protagon—whatever the nature of its constituents might be—was nothing more than a mixture of different substances. The claims of Liebreich were acknowledged to be based on faulty observation, and the protagon controversy seemed to have reached a final settlement. This, however, proved far from being the case, and protagon, which seemed to be effectively buried in the early seventies, has been resurrected subsequently on more than one occasion. The second important period in the history of protagon began in 1879, when Gamgee and Blankenhorn [1879] opened the closed protagon question and presented data indicating that Diaconow's con-

clusions were based on insecure foundations. Further, these observers claimed to have completely confirmed Liebreich's results. In this connexion some further reference to Diaconow's work may render matters somewhat clearer.

There seems little doubt that Diaconow's observation that protagon was a mixture from which lecithin and cerebrin could be obtained was the chief factor in bringing discredit on Liebreich's statements. That Diaconow's protagon was a mixture is true, but it is highly probable that his substance was a different body from Liebreich's protagon. In fact, it would seem that Diaconow's protagon was really a mixture of lecithin (and kephalin) with Liebreich's protagon. Diaconow's method of preparation was in general similar to that employed by Liebreich—extraction of brain with alcohol at 40° and cooling the alcoholic extract to 0°, whereby a precipitate of impure protagon was obtained. As pointed out by Diaconow, this crude protagon would naturally bring down some lecithin with it in the course of precipitation. It is also clear that the nature of the precipitate formed must have been dependent to some extent on the concentration of the alcoholic solution, since lecithin and kephalin are easily precipitated from alcoholic solutions at 0°, provided they are not too dilute.

Therefore, in the experiments of both Diaconow and Liebreich it is obvious that the primary precipitates obtained on cooling the warm alcoholic solution must have contained some lecithin. The final state of this precipitate as regards its lecithin content would depend on the thoroughness with which it was subsequently washed with ether. That Diaconow's substance was insufficiently washed is obvious from his own statement. Diaconow, however, attributed the whole of the phosphorus of protagon to the lecithin present, yet he failed to obtain a phosphorus-free residue by ether extraction. Seeing that lecithin is exceedingly soluble in ether, the persistent presence of phosphorus in the ether-extracted residue ought to have suggested to this observer that all the phosphorus could not have been present as uncombined lecithin. Since a small part of the phosphorus was present as lecithin, Diaconow evidently *assumed* without any justification that lecithin accounted for all the phosphorus, and that a phosphorus-free body was also present—the cerebrin of Müller [1858]. In support of these assumptions, he produced no evidence whatever, and it is now known that his deductions were to a great extent fallacious, since the phosphorus of protagon is really accounted for by the presence of sphingomyelin. His statement as to the presence in protagon of a substance

of the nature of cerebrin was based on an experiment in which a phosphorus-free residue was obtained from protagon *after boiling with baryta water*.

It is surprising that Diaconow did not suspect that his protagon was probably different from that of Liebreich in that it contained lecithin. It is also difficult to understand how he could have assumed that all the phosphorus of protagon was due to lecithin present in the free form. Assuming that the phosphorus was actually present as lecithin, all the evidence pointed strongly to the conclusion that much of this lecithin must have been combined in some form in which it was insoluble in ether. If so, it became necessary to accept Liebreich's conclusion that protagon was the mother substance of lecithin. This conclusion, however, was just what Diaconow's work most strongly controverted. On the whole, an examination of Diaconow's investigations on protagon prove conclusively that he failed entirely to produce any direct evidence that protagon was a mixture, or that Liebreich's claims regarding the chemical unity of this substance were not fully justified.

Some of these points were considered by Gamgee and Blankenhorn [1879], who showed that Diaconow's criticisms of protagon were entirely valueless. These observers prepared protagon from dog and horse brains, according to Liebreich's directions. Since the protagon obtained was exactly like the body described by Liebreich, and retained its composition when recrystallised four or five times out of alcohol, Gamgee and Blankenhörn concluded that protagon was undoubtedly a chemical unit.

The subsequent development of the protagon story is a peculiar one. Gamgee and Blankenhorn's conclusions were accepted without demur by all chemists interested in the subject. Those who previously had firmly believed that Diaconow and his colleagues had finally disposed of protagon were now naturally as strongly convinced that they had been in error. The validity of Gamgee and Blankenhorn's alleged proofs of the unit nature of protagon was not questioned. With a wonderful unanimity Liebreich's conclusions were now accepted with as much readiness as they had formerly been rejected. This complete *volte face* was apparently justified by the results of researches which continued to be published for the next twenty years. Paper after paper appeared in confirmation of Gamgee and Blankenhorn's conclusions, and protagon seemed for a second time to be more strongly established than ever—Parcus [1881], Baumstark [1885], Kossel and

Freytag [1893], Ruppel [1895], Zuelzer [1899], Noll [1899], Ulpiani and Lelli [1902].

One investigator alone during all these years steadfastly refused to come into line and accept the orthodox views. Year after year Thudichum [1874-1896] produced evidence, based on careful and extensive researches, that protagon was after all but a mixture of substances which could be separated to a great extent by repeated recrystallisation from alcohol.

With ever-increasing bitterness he assailed everybody who refused to accept his own conclusion that protagon had no claims to be considered as a chemical unit. In spite of the extreme if somewhat misplaced vigour with which Thudichum conducted his campaign, no impression whatever was produced on his opponents. For more than twenty years Thudichum was but a voice crying in the wilderness, and the chemical individuality of protagon was still firmly believed in. It is probable that the small amount of attention bestowed on Thudichum's work both here and in other connexions was in a great measure due to his unfortunate use of personal methods of attack in controversies, which should have been entirely impersonal. Thudi chum's persistence, however, seemed at last to bear fruit, and his conclusions received support from an observation made by Wörner and Thierfelder [1900] that on treatment of protagon with a mixture of alcohol and benzene a phosphorus-free body was obtained. This body they called *cerebron*. The residue left after the separation of cerebron had the appearance of ordinary protagon, yet all former protagons must have contained this substance. Another phosphorus-free body was also obtained. These results indicated that protagon was undoubtedly a mixture, a conclusion which was further supported by certain variations found in the analytical figures of some of Thierfelder's specimens.

Koch [1902] treated protagon with glacial acetic acid two or three times, and isolated a substance free from phosphorus which he took to be cerebrin. He considered that protagon was a mixture of lecithin, kephalin and cerebrin. Lesem and Gies [1903] also advanced evidence that protagon was not a unit substance. By 1904 it appeared to be generally accepted that this much-discussed body was undoubtedly a mixture [Koch, 1904; Hammarsten, 1904].

Although protagon was now buried for the second time, it did not enjoy a long repose. Another epoch in its history began in 1904, when a publication by Cramer [1904] appeared claiming to have once

more established the chemical unity of the substance. This paper formed the starting-point for a renewal of the old discussion as to the nature of protagon, the principal protagonists being Cramer, who upheld Liebreich's contentions, and Rosenheim and Tebb, who, along with Gies and his collaborators, refused to believe in protagon. The discussion was carried on with a good deal of the vigour which characterised the older controversies, and which seems to be evoked by investigations on this particular substance. It is now, however, generally accepted that the evidence is altogether in favour of Rosenheim and Tebb's conclusion that protagon is a mixture of cerebrosides and phosphatides.

Cramer contended that the reasons brought forward by Wörner and Thierfelder [1900] and by Lesem and Gies [1903] against the chemical individuality of protagon were not conclusive. He claimed that the protagon investigated by these observers was impure,[1] and that the cerebron which Thierfelder obtained from protagon was identical with a substance previously isolated by Gamgee [1880] from brain tissue, and called by him pseudo-cerebrin (p. 122). This body was extracted from brain by alcohol at 45°, and so would naturally be present in protagon provided no special steps were taken to ensure its removal. Cramer argued that the protagon of Gamgee was a pure substance, and based much of his defence of protagon on this assumption.

From the properties of pseudo-cerebrin, it must have been obvious to Gamgee that many of the older protagons contained this body. Indeed, one is tempted to ask whether, after discovering pseudo-cerebrin, Gamgee had not of necessity the suspicion forced upon him that the protagons of Gamgee and Blankenhorn [1879] also contained pseudo-cerebrin, and were therefore mixtures. Whether or not this was so is unknown, for he published no more on the subject. It is certain that all protagons must have contained this substance, so that Cramer's observations regarding pseudo-cerebrin rather increased than decreased the probability that protagon was a mixture of pseudo-cerebrin (cerebron, cerebrin) with other substances.

Like other investigators, Cramer found that one of his specimens of protagon, prepared in the same way as the others, differed considerably in composition from average protagon. Following Kossel and Freytag [1893], he assumed that this substance represented one of a group of different protagons, and suggested that the members of this

[1] Cramer [1908] afterwards admitted that the protagons of Lesem and Gies were pure.

alleged group should be called homo-protagons to distinguish them from ordinary protagon. Thus another indication of the non-unit nature of protagon was obscured by the introduction of an unnecessary name. The assumption of the existence of homo-protagons led directly to the idea held by the Cramer school that protagon may be a mixture of *homologous protagons*, a view advanced by Fränkel [1909].

Cramer's claims were thoroughly examined by Posner and Gies [1905 ; 1905, 1], who as the result of a long and careful investigation, brought forward evidence that should have ended the controversy. They showed that protagon was a mixture of substances in which a phosphorus-free body or bodies were associated with one or more substances containing relatively large proportions of phosphorus : the exact nature of these components was not known. In confirmation of the results of Thudichum [1879 ; 1880, 1] and of Lesem and Gies [1902] they showed that " by fractionation at the same or different temperatures in 85 per cent. alcohol, under conditions that could not effect chemical decomposition, protagon was partitioned into products very dissimilar in phosphorus- and sulphur-contents." They also found that Cramer's method yielded typical protagon " which could be fractionated without chemical decomposition into products of variable phosphorus content similar to those obtained from protagon prepared by other methods."

Lochhead and Cramer [1907] refused to accept the conclusions of Posner and Gies, and argued that strong evidence of the unit nature of protagon was afforded by the fact that after ten times repeated crystallisation from alcohol the crystals of protagon separating out had the same phosphorus percentage as the residue in the mother liquor and incidentally agreed in this respect with Gamgee's protagon. The results of the *fractional* crystallisation of the purified protagon, Wilson and Cramer [1908] accounted for by the assumption that treatment with alcohol at 40° for fourteen hours decomposed protagon.

On careful examination it appeared that one important difference between the ordinary crystallisations used for purifying protagon and the subsequent " fractional crystallisation " was that, in the former case, the protagon separating from alcohol on each recrystallisation was dissolved in fresh alcohol *without being previously dried*, while in the process of fractional crystallisation, the protagon *was dried* before being dissolved in alcohol. This experiment, therefore, suggested that dry protagon differed from moist protagon in its behaviour towards alcohol, and might even indicate that moist (hydrated ?)

protagon which had never been dried, was really composed of substances present in some form of very feeble combination which was destroyed on drying.

That moist protagon could be fractionated as easily as dry protagon was evident from an experiment of Rosenheim and Tebb [1909], in which it was shown that protagon obtained by Cramer's method was easily divided into fractions containing varying percentages of phosphorus. This sample of protagon *had not been dried during the processes of recrystallisation*, and yet under conditions which, according to Cramer, do not give rise to decomposition, the various fractions gave the results indicated below:—

	Phosphorus Percentage.
Original " pure " protagon . . .	0·98
1st recrystallisation	0·66
5th ,, ...	0·27
7th ,, ...	0·13
Fraction from mother liquor . . .	2·54

Further, Gies [1907] pointed out that the figures of Posner and Gies were really of no significance in the sense advocated by Cramer, since the physical qualities of the precipitates from alcohol, and the residues obtained from the corresponding filtrates showed that they were not identical substances. He further argued that the slight difference in the phosphorus percentage [1] of these substances was of sufficient importance to suggest of itself that they were not identical products. Thus, while the fact that protagon which had been recrystallised ten times from alcohol had the same percentage of phosphorus as the mother liquor, at first sight suggests that this product *might be* a chemical unit, it offers *per se* no *proof* whatever that this is so, and could only be advanced in support of this contention if other supporting evidence were forthcoming. Such evidence as we have, all points to the opposite conclusion—that protagon is a mixture.

The observations of Posner and Gies were confirmed by Rosenheim and Tebb [1907], who by means of somewhat different methods arrived at similar conclusions. These observers strongly emphasised the fact that by fractional crystallisation with acetone and other solvents protagon could be split up into substances of varying nitrogen

[1] The extraction was carried out both by Posner and Gies and by an independent observer: in each case the percentage of phosphorus in the precipitate from alcohol was lower than that from the filtrate, so that the difference naturally indicated something more than experimental error.

and phosphorus content. These general conclusions of Rosenheim and of Gies were criticised by Wilson and Cramer [1908], who maintained that many of those results had no bearing on the question at issue, since, in their opinion, they were obtained from material *called* protagon, which was not identical with protagon, but represented a crude product containing protagon together with other substances. They admitted that there was evidence, based chiefly on the work of Gies and his collaborators, that pure protagon when subjected to a "process of *fractional* crystallisation" could be split into substances differing widely in their solubilities and in their phosphorus content [Cohen and Gies, 1907].

From the mass of experimental work carried out on protagon it was now accepted by all investigators that this body consisted chiefly of two classes of substances, one of which was poor in phosphorus (galactolipins), while the other was comparatively phosphorus-rich (the phospholipin, sphingomyelin).

The admission by Wilson and Cramer that protagon could be divided into different substances by "fractional crystallisation" demanded, from their point of view, the obvious supposition that during this process decomposition had taken place. Since fractional crystallisation as used by Posner and Gies consisted in the treatment of protagon with a quantity of warm alcohol over periods lasting many hours, it was necessary to show that the prolonged action of warm alcohol on protagon resulted in decomposition. A sample of protagon was subjected to the action of 80 per cent. alcohol at 44° for twenty-two hours, and then compared with a similar sample which had not undergone this treatment. The results showed that definite changes were produced in the specific rotation and refractive index of protagon so treated, and from this Wilson and Cramer argued that warm alcohol decomposed protagon. Some of the figures which they obtained were as follows. The protagon investigated was dissolved in pyridine:—

	Specific Rotation.	Refractive Index of 3 Per Cent. Solution at 30°.
(1) Protagon (before alcohol treatment) .	6·66	1·5034
(2) Protagon (after alcohol treatment at 44° for 22 hours)	13·08	1·5038

From these figures it is clear that prolonged action of warm alcohol does produce a marked change in the specific rotation of

the substance.[1] There is no reason to ascribe this to "decomposition."

Such a change tells with equal force for the presence of a mixture of optically active substances, one or more constituents of which become racemised by heating, and cannot be considered as evidence in support of the chemical unity of protagon [Rosenheim and Tebb, 1909].

Another argument used by the Cramer school in support of their claims for protagon, was the fact that samples of protagon obtained by various investigators possessed a remarkably constant chemical composition, as indicated by elementary analysis. This similarity is well indicated in the figures quoted by Wilson and Cramer, and given below :—

Investigator.	C. Percentage.	H. Percentage.	N. Percentage.	P. Percentage.	S. Percentage.
Gamgee . .	66·39	10·69	2·39	1·06	—
Baumstärk .	66·48	11·12	2·35	1·02	—
Ruppel . .	66·29	10·75	2·32	1·13	0·096
Lesem and Gies	66·11	10·90	2·02	1·23	0·77
Cramer . .	66·37	10·82	2·29	1·04	0·71

Similar as are these results, it is obvious that *per se* they supply no proof of the unit nature of protagon. No doubt, *when considered quite apart from other evidence*, they suggest that protagon is not a mixture. Though Rosenheim has pointed out that a review of all the analyses of protagon in the literature furnish figures which are often by no means in such close agreement as those given above, it must be admitted that the analytical data obtained from different protagons agree, on the whole, remarkably well. This agreement is a superficial one, and is only apparent in products prepared under certain given conditions and recrystallised from one solvent (alcohol) under equally restricted conditions [Rosenheim and Tebb, 1909]. It is dependent on the fact that the substances of which protagon is composed have somewhat similar solubilities in cold alcohol, and so cannot be readily separated under the conditions usually observed in the preparation of protagon. A similar phenomenon holds in the case of lecithin which, though a mixture of two substances, cannot be separated by solvents into its components, but remains of approximately the same composition as the original lecithin [MacLean 1915]. Another example is seen in the case of phytosterol, which on recrystallisation from alcohol, usually

[1] Rosenheim and Tebb [1908, 1] could not obtain this result.

furnishes a product of constant composition having the same chemical and physical properties. This substance, ever since its discovery by Hesse [1878], was assumed to be a chemical unit, until Windaus and Hauth [1906] demonstrated that it was a mixture of two substances. Margaric acid may also be referred to as a product of this nature [Holde, 1905].

It therefore follows, that the recrystallisation of a substance from alcohol without change in its composition, is no proof of its chemical entity. On the other hand, if " pure " protagon could be separated into fractions differing in chemical composition, by recrystallisation from alcohol or other solvents, and under conditions excluding the possibility of decomposition, it must be a mixture. Such evidence would be incontrovertible in establishing the nature of protagon, for, unlike many of the results brought forward in favour of the unit nature of this body, this evidence would bear only one possible interpretation. The results of recrystallisation of protagon from solvents under suitable conditions must therefore be accepted as the crucial test, for or against the view, that protagon is a chemical entity.

In view of the alleged effect on protagon of prolonged treatment with hot alcohol, Wilson and Cramer [1908] proposed a method for the preparation of protagon in which they used boiling alcohol, but restricted its use to a very short space of time (one to two minutes). These observers stated that the substance prepared in this way was pure protagon, and that the only conditions necessary for recrystallisation from alcohol, without change in its composition, was exposure to the hot solvent for a short period. These claims were examined by Rosenheim and Tebb [1908], who prepared protagon according to Wilson and Cramer's instructions. They found that by simply varying the proportion of protagon to alcohol, variations in the phosphorus percentage of over 50 per cent. were obtained; on the other hand, as might be expected, little or no change in the phosphorus content was observed when the amount of alcohol used was small.

Even more striking evidence that protagon is a mixture was obtained when pyridine was used as a solvent. Protagon is fairly soluble in pyridine at 30° to 45°, and a precipitate forms on cooling. This precipitate is very different from the original protagon, as the appended figures show :—

	Phosphorus Percentage.	Nitrogen Percentage.
Original protagon	1·07	2·46
Fraction I. (insoluble in pyridine at 15°) .	2·51	3·03
Fraction II. (precipitated by acetone at 0°) .	0·09	1·73

This evidence of the non-unit nature of protagon was as complete as could reasonably be required, but it was further strengthened by results obtained from protagon, when a variety of different solvents and mixtures of solvents were employed [Rosenheim and Tebb, 1909, 1910]. The extraordinary variation in the phosphorus percentage of fractions obtained from so-called pure protagon is very remarkable, as may be seen from the following experiments showing variations from 0·05 per cent. to 2·6 per cent. obtained in a single recrystallisation of a protagon containing 0·99 per cent. phosphorus :—

Solvent.	Proportion of Mixed Solvents.	P. Percentage in Original Protagon.	P. Percentage in Recrystallised Substance.
Trichlorethylene . . .	—	0·99	0·70
,, plus alcohol .	1 : 4	—	0·48
,, ,, acetic acid	1 : 2	—	0·05
,, ,, ,, ,,	1 : 3	—	0·36
Chloroform plus acetone .	1 : 3	—	0·83
,, ,, acetic acid .	1 : 2	—	0·08
,, ,, alcohol .	1 : 2	—	0·60
Pyridine	—	—	2·60

Rosenheim and Tebb [1908, 2] also showed that an artificial mixture of galactolipins and sphingomyelin, in the proportions in which they occur in protagon, had the same composition and properties as protagon, and could be recrystallised from alcohol without change.

Further, the same observers demonstrated that the different lipins of brain could be separated by consecutive extractions with different solvents. This method of selective extraction gave the results indicated, the dried brain being treated with the different solvents in the order given [Rosenheim and Tebb, 1910, 1] :—

Solvent.	*Lipins extracted.*
1. Cold acetone	= (Cholesterol).
2. Ether	= Lecithin and kephalin.
3. Pyridine (30° to 40°)	= Galactolipins.
4. Pyridine (45°)	= Sphingomyelin.

In this experiment the highest temperature employed was 45°, so that decomposition was practically excluded, yet the constituents of

alleged protagon were extracted in separate fractions. The results show that galactolipins and sphingomyelin exist in the free state in the brain, and this view must be accepted. It is true that the Cramer school [Pearson, 1914] attributed these results to a decomposing action of pyridine on the hypothetical protagon present in the brain, yet Cramer's physical constants of protagon were obtained from solutions of this product in pyridine. If pyridine decomposes protagon it must surely be admitted that no importance can be attached to these constants; Cramer, however, bases his statement that protagon is decomposed by warm alcohol entirely on results obtained from solutions of protagon in warm (30°) pyridine.[1]

These results appear to furnish conclusive evidence that protagon is a mixture, for it is impossible to interpret them in any other light. Cramer [1910] admitted the correctness of Rosenheim's observations in the recrystallisation experiments described, but argued that they were not valid, since the protagon of the latter was not true protagon but a mixture. It is, however, impossible to accept the claim that Rosenheim's specimens differed from those of Cramer, as many of them were obtained by scrupulously following Cramer's directions; if they did differ in any way, this affords further proof of the non-unit nature of protagon, for it is certain that any unit substance must have yielded exactly similar products to both observers, since their methods of preparation, in many cases, were absolutely identical. In spite of all this evidence that protagon is a mixture, Pearson [1914] made still another endeavour to rehabilitate the substance, by estimating the effect of protagon on the boiling-point of chloroform.

Much more attention must be paid to the purity of the substance, and to the elimination of impurities possibly introduced in the method of preparation of the decomposition products, before any significance can be attached to such irregular results as those obtained in Pearson's experiments.

Protagon is nothing more than a mixture of galactolipins and sphingomyelin with traces of other bodies.

The history of its discovery and the elucidation of its composition

[1] It might well perhaps be argued that pyridine at 30° to 40° [Rosenheim] decomposes protagon, while pyridine at 30° (the temperature adopted by Cramer) does not do so. Though this is improbable, it may be pointed out that Rosenheim and Tebb [1908, 3, 4] have proved that protagon can be fractionated by pyridine at exactly 30°. The only obvious answer to this would be that such a protagon was, from Cramer's standpoint, an impure product. Such an explanation is inadmissible, since the protagon in question was obtained by Wilson and Cramer's method.

furnish an excellent instance of the difficulties in determining the chemical identity of such substances. It has no longer any claims to be considered as a definite chemical individual, and henceforth must be classified with the other " alleged lipins."

(2) CARNAUBON.

Carnaubon [Dunham and Jacobson, 1910] was the name given to a substance isolated from ox kidneys by Dunham [1905] which was very similar to Liebreich's protagon. The composition of this substance was further studied by Cramer [1904] and Dunham [1908] : the latter investigator isolated from it an acid of the composition $C_{24}H_{48}O_2$, which he considered identical with carnaubic acid ; the existence of carnaubic acid itself is, however, very doubtful [Röhmann, 1905 ; Matthes and Sanderr, 1908 ; Lewkowitsch, 1913]. MacLean [1912, 1, 2] obtained a similar substance from horse kidney, but found that his substance contained a water-soluble nitrogenous impurity. On the removal of this impurity, a product was obtained with a N : P ratio of exactly 2 : 1, closely resembling sphingomyelin. Rosenheim and MacLean [1915] showed that the alleged carnaubic acid was identical with lignoceric acid, and that phrenosinic acid and sphingosine were also present among the products of hydrolysis of carnaubon, in addition to the galactose and choline isolated by Dunham. Indeed, carnaubon represented a variable mixture of lipins mainly consisting of galactolipins (phrenosin and kerasin) and sphingomyelin ; it was a similar mixture of substances to Liebreich's protagon. The kidney " protagon " mixture seems, however, to contain more sphingomyelin and less galactolipins than the corresponding brain " protagon."

(3) PARANUCLEOPROTAGON.

A compound of " protagon " and protein was described by Ulpiani and Lelli [1902] ; the investigations of Steel and Gies [1907] and Posner and Gies [1905] showed that it was a mixture of substances and not a chemical unit.

(4) CUORIN.

In the previous edition of this monograph, cuorin was included with the phospholipins, lecithin, kephalin and sphingomyelin, the claims of which to be regarded as chemical individuals had already been established. It was then stated that it was only " with all

reserve" that cuorin could be regarded as a chemical unit, and the possibility was suggested that cuorin was simply kephalin contaminated with a phosphorus compound. Since there was no definite proof that the substance was not a mixture, the question had necessarily to be left open. Such proof has now been supplied by the work of Levene and Komatsu [1919, 1] and of MacLean and Griffiths [1920], and MacLean's suggestion that cuorin was merely kephalin mixed with some phosphorus-containing impurity has been entirely substantiated.

Cuorin was the name given by Erlandsen [1907] to a phospholipin isolated from the ether extract of heart muscle. It was insoluble in alcohol, and was at first thought to be kephalin. It differed, however, from kephalin in having two atoms of phosphorus in the molecule, and on this account Erlandsen recognised it as a new mono-aminodiphosphatide and called it cuorin (Ital. *cuore* = heart).

Closely similar substances were also obtained from horse kidney [MacLean, 1912, 2], from liver [Baskoff, 1908], and from egg-yolk [MacLean, 1909, 2]. Baskoff's substance was called "heporphosphatide," and had a N : P ratio of 1 : 1·5. Levene and Ingvaldsen [1920, 1] showed that heporphosphatide, like cuorin, consisted of a mixture of kephalin with its degradation products; when sufficient care was taken to prepare this substance from perfectly fresh tissues, kephalin and not heporphosphatide was obtained.

The elementary analysis of cuorin gives for hydrogen and carbon practically the same results as kephalin, while the nitrogen and phosphorus figures differ considerably from those of kephalin. The different preparations of cuorin analysed by Erlandsen gave very consistent results, as seen in the table, where the figures obtained for certain cuorin-like bodies are also given:—

Observer.	Source of Material.	C.	H.	N.	P.	N : P Ratio.
Erlandsen [1907]	Ox heart	61·86	8·93	1·01	4·43	1 : 2
		61·46	8·92	1·02	4·41	
		61·57	9·11	—	—	
" "	" "	61·76	9·18	1·01	4·46	1 : 2
		61·52	9·09	1·03	4·52	
" "	" "	—	—	—	4·46	1 : 2
		—	—	1·01	4·50	
MacLean [1912, 2]	Horse kidney	60·4	10·2	1·04	4·45	1 : 2
" [1909, 2]	Egg-yolk	59·12	9·44	0·812	3·59	1 : 2
Baskoff [1908]	Liver	61·12	8·95	1·23	4	1 : 1·5

In its physical and chemical properties, cuorin closely resembled kephalin. Levene and Komatsu [1919, 1] during their investigation

into the structure of kephalin, succeeded in fractionating cuorin and resolving it into kephalin and various degradation products derived from this substance. It was clear, therefore, that cuorin must have contained kephalin, and had no longer any claim to be considered as a chemical individual. MacLean and Griffiths [1920] arrived at the same result in a rather different manner. They showed that in the preparation of cuorin, if very fresh heart tissue were dried and extracted as rapidly as possible the substance obtained was not cuorin (N : P = 1 : 2), but slightly impure kephalin (N : P = 1 : 2). Cuorin must therefore be regarded as a mixture of kephalin with its degradation products, which latter contain a higher percentage of phosphorus than kephalin.

(5) Alleged Lipins Isolated by Fränkel and his Colleagues.

While the evidence at our disposal at present points to the conclusion that all organs contain certain amounts of lecithin and kephalin, and probably sphingomyelin and galactolipins as well, certain other lipins, differing from those mentioned, have been stated to be present in certain organs.

Many of these substances have been isolated and named by Fränkel and his collaborators, but it is no exaggeration to say that Fränkel has produced no reliable evidence that any of his alleged new bodies exist. Indeed, it is certain, as pointed out below, that several of Fränkel's new products were mixtures of lecithin with other substances.

These new bodies were generally obtained in the form of the cadmium chloride combination, which was purified by precipitating its benzene solution with alcohol. From the behaviour of carnithin-cadmium chloride combinations, carnithin must have been present in practically all cases. The nitrogen : phosphorus ratio affords no reason for accepting the product as a definite lipin body. By precipitating extracts of organs with cadmium chloride according to Fränkel's procedure, products with almost any N : P ratio can be obtained.

Vesalthin (N : P = 1 : 1) [Fränkel and Pari, 1909; Fränkel, Linnert and Pari, 1909].

This name was given by Fränkel and Pari [1909] to a substance isolated by them from ox pancreas. The substance had the same

N : P ratio as lecithin, and it is quite certain from the account of its preparation that the final alcoholic solution from which the cadmium chloride compound was obtained must have contained lecithin. Vesalthin could not have been a pure substance [MacLean, 1914]. A body very similar to vesalthin was isolated by Erlandsen from ox heart; it was also shown to be a mixture of lecithin with other bodies [MacLean, 1914].

Diamino-monophosphatide (N : P = 2 : 1).

Alleged substances of this nature have been isolated from ox heart [Erlandsen, 1907] and from kidney [Fränkel and Nogueira, 1909]. Both products were obtained as cadmium chloride compounds. MacLean [1914] showed that Erlandsen's substance was a mixture of lecithin contaminated with carnithin; the method of preparation employed by Fränkel suggests that Fränkel and Nogueira's product is a similar mixture. The only diamino-monophosphatide hitherto isolated from the tissues is sphingomyelin.

Neottin (N : P = 3 : 1).

This was the name given by Fränkel and Bolaffio [1908] to a product they isolated from egg-yolk. This substance appears to be identical with the carnaubon of Dunham and Jacobson, which it is interesting to note was at first considered by these latter authors to be a triamino-monophosphatide. It is merely a mixture of sphingomyelin and galactolipins with some nitrogenous impurities [Rosenheim and MacLean, 1915].

Kidney Triamino-diphosphatide (N : P = 3 : 2).

This was prepared by Fränkel and Nogueira [1909] from kidneys, and from its method of isolation is obviously a mixture of lecithin and carnithin.

Sahidin (N : P = 3 : 2).

Fränkel and Linnert [1910] gave this name to a product derived from a petroleum ether extract of brain. Fränkel and Kász [1921] showed subsequently that it was a mixture from which pure lecithin could be isolated.

Leukopoliin (N : P = 10 : 2).

Fränkel and Elias described this substance in 1910. There is no evidence whatever that this body has any claim to be considered as a chemical unit.

Dilignoceryl-n-diglucosamin-monophosphoric Acid Ester (N : P = 2 : 1).

The isolation of this substance is described by Fränkel and Kafka [1920] but Thierfelder and Klenk [1925] were unable to confirm its existence. Like Thudichum's myelin, it is precipitated by an alcoholic solution of lead acetate, but differs from Thudichum's substance in that it gives a lead compound soluble in ether. On hydrolysis in acid solution, lignoceric acid, glucosamine and phosphoric acid were isolated [see p. 122].

(6) Jecorin

The case of jecorin furnishes an instance of the association of lipin with carbohydrate; in view of the frequency with which such substances are met with in plants, the history of jecorin is of especial interest.

Jecorin was the name given by Drechsel [1886] to a product which he isolated from horse liver. The liver was minced, extracted with absolute alcohol, the alcoholic extract concentrated at 40° to the consistency of a syrup and the syrup treated with absolute alcohol until no more substance dissolved. The residue was then taken up in ether and from the ethereal solution jecorin was precipitated by the addition of absolute alcohol. On further purifying this jecorin, a yellowish-brown mass was obtained, which, on drying, formed a very hygroscopic yellowish-white powder. This powder was insoluble in absolute alcohol and in dry ether, but dissolved in wet ether. In water it first swelled up and then dissolved. When tested with Fehling's solution a well-marked reduction was obtained. On analysis, jecorin was found to contain carbon, hydrogen, nitrogen, sulphur, phosphorus and sodium. A similar product was isolated from the liver of the dolphin [Drechsel, 1896].

Drechsel's observations were confirmed by Baldi [1887] who, using an almost identical method, prepared jecorin from rabbit and dog livers and from other organs.

Jecorin was also found in blood, but its alleged presence in this tissue was based more on conjecture than on actual experiment. In

investigations carried out on blood prior to Drechsel's discovery of jecorin, it was found that blood contained, besides fermentable sugar, other reducing non-fermentable substances [Otto, 1885]. The nature of these substances was unknown, but on account of certain supposed superficial resemblances to jecorin it was assumed that they were identical with jecorin [Jacobsen, 1892, 1895; Henriques, 1897; Bing, 1898, 1899; Letsche, 1907]. No analytical figures were furnished by any investigator, and the alleged existence of jecorin in blood was based on entirely valueless observations. Indeed, it is known that some, at least, of the so-called jecorins of blood consisted of glycuronic acid compounds [Mayer, 1906, 1]; Mayer also showed that at most 2 per cent. of the sugar of blood could possibly be present as "jecorin," and regarded its existence in the blood as doubtful.

Jecorin, or a similar body, has been found in spleen and in brain [Baldi, 1887], in muscles [Baldi, 1887; Erlandsen, 1907], in heart [Erlandsen, 1907], in adrenals [Manasse, 1895], in bone marrow [Otolski, 1907], and in bile [Hammarsten, 1902].

The chemical nature of jecorin was investigated by Manasse [1895] who, on hydrolysis of a specimen prepared from liver according to Drechsel's directions, obtained choline, fatty acids, glycerine, phosphoric acid, glycerophosphoric acid and glucose. Since these products, with the exception of glucose, were identical with those obtained from lecithin, Manasse concluded that jecorin was a lecithin complex containing glucose.

Manasse's statements were further confirmed by Bing [1898, 1899], who prepared an artificial lecithin-glucose complex by dissolving sugar in an alcoholic solution of lecithin. On evaporating the alcohol and extracting the residue with ether, it was found that the ether extract contained a product which gave a precipitate on the addition of alcohol. Since this product reduced Fehling's solution, Bing concluded that jecorin was lecithin-glucose which contained small amounts of other substances as impurities.

Mayer [1906, 1], in extension of Bing's work, isolated the artificial lecithin-glucose body, by precipitation of its ethereal solution with alcohol. He obtained products containing various amounts of sugar up to 84·5 per cent., and concluded that jecorin was a mixture of lecithin-glucose complexes containing varying amounts of sugar. A specimen of liver-jecorin containing about 14 per cent. of sugar was shown by Baskoff [1908] to contain the same amount of sugar after repeated precipitation by alcohol from its ethereal solution: similarly,

Meinertz [1905, 1] showed that a sample of liver-jecorin, which also contained about 14 per cent. of sugar, had the same sugar percentage as the original product, after repeated precipitation with alcohol.

Though the investigations of Bing and others strongly suggested that jecorin was not a unit substance, the impossibility of changing the sugar content of jecorin by repeated precipitation by alcohol, as shown by Meinertz and by Baskoff, seemed to furnish some ground for regarding the product as something more than a mechanical mixture. Certain observers, indeed, still firmly held the view that jecorin was a definite chemical compound [Waldvogel, 1903; Waldvogel and Tintemann, 1904, 1906; Letsche, 1907], while others such as Meinertz [1905], Siegfried and Mark [1905], Mark [1907] as firmly believed that it was a mixture.

Jecorin a Mixture.

In considering whether jecorin represents a unit substance or a mixture it is important to compare the analytical data published by different observers. The figures show that the different products which the various investigators called jecorin were by no means identical substances, even when derived from the same organ.

Observer.	Source of Jecorin.	C.	H.	N.	S.	P.	Na.	Ratio P : N.
Drechsel [1886] . .	Horse liver	51·5	8·2	2·9	1·5	3·5	2·7	1 : 1·8
Baldi [1887] . . .	Dog ,,	46·8	7·9	4·5	2·4	2·5	3·7	1 : 3·8
Siegfried and Mark [1905]	Horse ,,	39·7	6·4	5·2	2·2	1·9	5·9	1 : 6·0
Mayer [1906] . . .	,, ,,	55·8	4·4	2·6	1·5	1·4	3·5	1 : 4·1
Baskoff [1908] . .	,, ,,	50·39	7·29	3·12	2·89	1·82	2·8	1 : 2·3

The variability of these results is so great that jecorin at once loses all claim to be considered as a unit body. They show the kind of figures that might be expected from a variable mixture in which the exact amount of the different compounds present depended on certain variable factors operating in the course of its preparation.

Further evidence of the non-unit nature of jecorin is afforded by statements as to carbohydrate contents of various preparations.

Mayer's [1906, 1] jecorin contained 18·2 per cent. of sugar, while that of Meinertz [1905, 1] and of Baskoff [1908] had about 14 per cent. On the other hand, Offer [1904] obtained from liver a specimen which was carbohydrate-free. Some jecorins did not reduce Fehling's solution directly [Offer, 1904; Meinertz, 1905; Waldvogel and

Tintemann, 1906; Baskoff, 1908], while others reduced immediately [Drechsel, 1896; Baldi, 1887]. Adrenal-jecorin reduced only after being subjected to prolonged hydrolysis with sulphuric acid [Manasse, 1895]. Sakaki [1913; 1913, 1] obtained similar results with placenta-jecorin, which he thought was of the same nature as Manasse's substance. How widely the two substances differed is obvious from the fact that the N : P ratio of Manasse's product was 3 : 2, while that of Sakaki's was about 1 : 6. Indeed, from a survey of the literature, it seems that no two samples of jecorin ever furnished similar analytical data, and even the statements as to solubility vary considerably [Siegfried and Mark, 1905].

It is also significant that Baskoff [1908] could not obtain jecorin from the liver, when the organ was treated according to Erlandsen's method [1907]. From this it would appear that jecorin is an artificial product formed during the processes described by Drechsel for the isolation of this substance. This view is in accord with the results of Waldvogel [1903] and Waldvogel and Tintemann [1904], who found much more jecorin in autolysed livers and in livers of dogs poisoned by phosphorus, than in normal livers [see also Meinertz, 1905]. According to Baskoff [1909, 1], alcohol poisoning does not affect the jecorin content of the liver, but markedly reduces the lecithin content.

Further, it was shown by Siegfried and Mark [1905] that jecorin could be divided into various fractions of very different composition.

These observations furnished strong evidence that jecorin was a mixture, and the only point which seemed somewhat difficult to reconcile with this view was the fact already mentioned that certain preparations of liver-jecorin contained a definite amount of sugar (about 14 per cent.), and that the sugar could not be removed, or its percentage reduced, by precipitating jecorin from its ether solution by means of alcohol. These difficulties were more apparent than real, for it is well known that certain phospholipins, such as lecithin, have the peculiar property of forming physical complexes with many organic substances [Bing, 1901]. It is also recognised that these complexes cannot be readily separated into their constituents by repeated precipitation from their solutions by means of alcohol. If, therefore, the concentration of sugar in a liver was such, that lecithin, or some other phospholipin present, took up about 14 per cent., one would expect no change in the sugar percentage after several precipitations with alcohol. That this particular amount of sugar was found in two or three different samples of liver-jecorin was obviously accidental, since

some samples of jecorin from liver contained much more sugar, namely, 18·2 per cent. [Mayer, 1906, 1], and others no sugar at all [Offer, 1904]. Neither the amount nor the behaviour of sugar of jecorin furnishes any evidence in favour of the unit nature of jecorin, while all the other evidence recorded is only to be reconciled with the view that jecorin is a mixture. According to Meinertz [1905, 1] the sugar of jecorin can be removed by dialysis, and Scott [1916] has made the interesting observation that the sugar of lecithin-glucose can be obtained free, in solution, by removing the lipin with colloidal iron.

The Nature of Jecorin.

From the method of preparation of jecorin, as given by Drechsel, it is quite certain that this substance must have contained large amounts of kephalin. Though kephalin is comparatively insoluble in alcohol, it appears to be relatively soluble in alcoholic solutions containing lecithin, and is always present in considerable amount in alcoholic extracts of tissue. Indeed, Drechsel's description of the physical properties of jecorin would do very well for kephalin. Like kephalin, it was insoluble in absolute alcohol: it was also insoluble in dry ether, but dissolved in *wet* ether, properties which Parnas [1909] showed to be characteristic of kephalin. Like kephalin, jecorin first swelled up in water and then "dissolved." Jecorin contained sodium and so does kephalin [Thudichum, 1884; Parnas, 1909].

Although jecorin was supposed by Bing and others to be lecithin-glucose, it is clear that very little lecithin could be present, since this lipin must have been removed by the alcohol treatment which the jecorin invariably underwent.

It is quite certain that the bulk of jecorin must have consisted of kephalin, and the presence of sugar and other bodies is easily explained by the fact that kephalin, like lecithin, has a very marked tendency to form physical complexes with various organic substances [Fränkel and Neubauer, 1909; Thudichum, 1884].

Thus in the presence of sugar the formation of kephalin-glucose was to be expected. Jecorin represents not lecithin-glucose but kephalin-glucose [Frank, 1913], though no doubt small amounts of lecithin-glucose might be present. Another substance that must have been present to some extent is carnithin.

Jecorin is therefore to be regarded as a variable mixture consisting

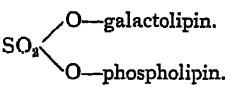
chiefly of kephalin and inorganic salts, together with certain organic substances (galactolipins, "protagon" sugar, glycogen, etc.), which owing to absorption, intersolubility and other physical phenomena, cannot be readily separated from the kephalin.

Indeed, from what we now know of the behaviour of the phosphatides, jecorin is exactly the kind of body we should expect to obtain as an artificial product, on treating liver according to Drechsel's directions for the preparation of jecorin.

(7) The Sulphatides of the Brain.

Thudichum [1884] first postulated the existence of a lipin in which the phosphoric acid was replaced by sulphuric acid. He obtained from human brain samples in which the ratio sulphur : phosphorus was 3 : 2 and 1 : 1 respectively, but he was unable to further separate these substances.

Koch [1907, 1] claimed to have separated a substance containing sulphuric acid, the latter being joined to the sugar in an ester-like combination, represented by the formula—



A sulphur-containing lipin entirely free from phosphorus was isolated by Levene [1912] from ox brain. It resembled the lipins in its physical properties, was dextro-rotatory and melted at 210°. At present it is not sufficiently characterised to be regarded as a chemical entity.

Fränkel and his colleagues consider that they have isolated two individual phosphosulphatides from brain and have obtained evidence of the existence of a third.

Cerebric Acid [Fränkel and Gilbert, 1921] was obtained from the fraction of the alcohol-soluble barium salts of protagon, which is soluble in benzene : part of this fraction was soluble in petroleum ether, and from this solution a substance was obtained having the ratio P : S : N : Ba = 1 : 1 : 3 : 2. Aminoethyl alcohol and cerebronic acid were obtained from it as hydrolytic products.

Hypocerebric Acid [Fränkel and Karpfen, 1925].—From the fraction of barium salts insoluble in benzene a triamino-monophosphate sulphatide ($C_{101}H_{152}O_{26}N_3PS$) melting at 196° was obtained. It gave

on hydrolysis phosphoric and sulphuric acids, glycerol, aminoethyl alcohol and a α-hydroxy-*n*-decoic acid melting at 161°.

The elementary analyses obtained for these various products are shown in the following table :—

	(1) Thudichum.	(2) Koch.	(3) Levene.	(4) Fränkel & Gilbert.	(5) Fränkel & Karpfen.
C	47·70	—	60·90	55·82	64·20
H	7·54	—	10·67	9·34	8·01
N	1·14	—	2·31	1·91	1·98
P	3·94	1·80	0·00	1·58	1·60
S	6·19	1·91	2·66	1·63	1·70

CHAPTER VI.

PLANT LIPINS.

THE difficulties encountered in isolating pure preparations of lipins from vegetable tissues appear to be much greater than is the case with animal organs. The chief obstacles encountered in the investigation of plant products of this nature are, to a great extent, dependent on the presence in the plant of large amounts of carbohydrate material which tend to form physical complexes of a "jecorin"-like nature with the lipins. It would also seem that certain of the methods employed in the case of animal tissues are unsuitable for the preparation of plant lipins. Our present knowledge of plant lipins is extremely limited, and we do not yet know with any certainty whether or not plant and animal lipins are identical. So far as it is possible to judge from the available literature, there is a certain amount of evidence pointing to the conclusion that no essential difference exists between the lipins of the two kingdoms. This view is by no means universally accepted, for certain observers assert that plant lipins are entirely different from those of animal origin. Thus Bang [1911] makes the following observations on this point "Die Pflanzenphosphatide unterscheiden sich sehr deutlich von der tierischen. Lecithin kommt, aller Wahrscheinlichkeit nach, im Pflanzenreiche nicht vor, und ebensowenig finden sich andere aus dem Tierkörper bekannte Phosphatide."

The question, as to the nature of plant lipins, opens up what promises to be a fertile field for future research, for, up to the present, the investigation of these bodies has been carried out by a comparatively small number of workers.

The application to plants of some of the newer methods used in the case of animal organs, might well result in a solution of some of the above problems connected with this subject. The principal observations on plant lipins hitherto carried out have dealt almost entirely with plant phospholipins.

Plant Phospholipins.

The earliest indications of the presence of bodies of a phospholipin nature in plants were afforded by the observations of Knop [1860] and of Töpler [1861] who isolated from certain plant tissues fatty extracts containing phosphorus. Shortly afterwards Hoppe-Seyler [1867] isolated a small amount of a substance closely resembling egg lecithin from the seeds of *Bertholletia excelsa ;* a similar product was obtained from peas, but in neither case was the lipin prepared in pure form.

From this time onward until quite recently it was taken for granted that the only phospholipin present in plants was " lecithin." That a phosphorus-containing lipin was of general occurrence in plant seeds was shown by Heckel and Schlagdenhauffen [1886], but the first definite indication of the similarity of this body to lecithin was afforded by the work of Jacobson [1889], who showed that one of the decomposition products furnished by plant phospholipins was choline. Shortly afterwards Schulze and Likiernik [1891] obtained from seeds lecithin-like substances which gave, on hydrolysis, choline, glycerophosphoric acid and fatty acids.

Estimations of Plant Lecithin.

In earlier investigations on plant lecithin much of the work consisted in estimating the amount of this product present in seeds and in other parts of plants. These estimations were carried out by extracting the tissue with ether and estimating the phosphorus percentage in the ether extract ; the lecithin content was then calculated from the amount of phosphorus found. By this method Töpler [1861] obtained the following data from air-dried seeds :—

	Percentage of Lecithin in Ether Extract.	Percentage of Lecithin in Dried Seeds.
Beans . . .	18·75	0·30
Vetches . . .	13·02	0·39
Peas . . .	30·46	0·61
Lupines . . .	7·55	0·37

Some results obtained by Beyer [1871] and later by Jacobson [1889] suggested that this method by ether extraction was unsuitable for quantitative purposes.

Jacobson extracted seeds with alcohol and estimated the phosphorus in the ether-soluble part of the residue from the alcoholic

extract. He found that this method yielded much higher results than the method of direct ether extraction, as may be seen from his figures :—

	Percentage of Lecithin in Ether Extract. (Calculated from P. Per Cent.)
Beans	64·04
Vetches	20·83
Peas	50·25
Lupines	50·00

While Jacobson's observations were quite correct, his explanation of them was wrong, for he concluded that the excess of phosphorus obtained by alcohol treatment was due to the extraction by alcohol of some ether-soluble body other than lecithin containing phosphorus.

The true explanation was afforded by Schulze and Steiger [1889], who showed that treatment of finely powdered seeds with ether dissolved only part of the lecithin present : to obtain the whole of the lecithin, extraction with hot alcohol was necessary. That the alcoholic extract of seeds which had already been treated with ether, actually contained lecithin and not some other phosphorus compound, was inferred by these observers from the fact that this extract yielded fatty acids and choline. This behaviour of seeds towards ether was explained on the assumption that part of the lecithin existed in combination with some other substance in the seeds, and that this compound was decomposed by hot alcohol [see also Maxwell, 1891]. It appears, therefore, that the lipins are held in the tissues of the plant just as they are in the animal tissues, and that in both cases, preliminary treatment with alcohol is necessary before the lipins can be satisfactorily extracted.

A number of quantitative estimations of various seeds were carried out by ether-alcohol extraction [Schulze and Steiger, 1889 ; Stellwag, 1890 ; Bitto, 1896 ; Stutzer, 1908 ; Vogeler, 1909, and others]. The results indicate that, on the whole, the amount of lecithin present in plants is small (see next page).

Further observations on the amount of lecithin in plant seeds are given by Schulze and his collaborators, also by Stromer and Fallada [1906], by Deiler and Fraps [1910], and by Parrozzani [1910].

It is obvious that the accuracy of this method of lecithin estimation depended on certain hypotheses :—

1. That the extraction of the seeds was complete.

Seeds.	Percentage of Lecithin Calculated from P. of Ether-alcohol Extract [Schulze and Steiger].
Lupinus luteus	(1) 1·55 (2) 1·59
Soja Hispida	1·64
Vicia Sativa	1·22
Faba vulgaris	0·81
Triticum vulgare	0·65
Secale cereale	0·57
Hordeum distichon	0·74
Linum usitatissimum	0·88

2. That the whole of the phosphorus found in the ether-alcohol extract of seeds was present in lipin combination, and that only one lipin (lecithin) was present.

The first of these hypotheses was combated by Bitto [1894], who maintained that the extraction of seeds by ether and alcohol according to Schulze and Steiger's method was incomplete. Schulze [1894] contended that Bitto's criticisms had but little weight, since seeds which had been treated by this method contained only small traces of phosphorus. Later [1904] he remarked that it was not quite certain whether alcohol at 60° completely extracted the lecithin from seeds, but to guard against decomposition he still recommended the use of alcohol at this temperature.

Schulze came to the conclusion that all the phosphorus of the alcohol and ether extracts was probably represented by lecithin, for no other phosphorus-containing substance, with the exception of phosphates, could be found in plants. Since phosphates were insoluble in both alcohol and ether, they could be excluded. He did not, however, entirely exclude the possibility that some phosphorus might be present which was not represented by lecithin, and stated that in any case the method gave maximum results [Schulze and Steiger, 1889; Schulze and Frankfurt, 1894; Schulze, 1904]. It was only in recent years that the presence of lipins other than lecithin, in plant extracts, was recognised, and the more general term phosphatides used instead of lecithin [Schulze and Winterstein, 1903; Winterstein and Hiestand, 1906; Schulze, 1908].

While this method of estimation gave a general idea of the lipin content of the tissues examined, it was by no means an ideal one, and the figures obtained could only be regarded as a very rough index of the lipin content. Schulze and Likiernik [1891] modified the above

method for obtaining and estimating lecithin. After treatment of the finely ground seeds with ether and then with alcohol at 50° to 60°, they dissolved the residue obtained from the ether-alcohol extract in ether, washed the ether solution with water, and finally evaporated the washed ether solution. The residue was " crude lecithin," from which a purer product was obtained by dissolving in hot spirit and cooling the solution, when an amorphous body separated which had the properties of lecithin [see also Schulze and Frankfurt, 1894; Stoklasa, 1895; Schulze, 1897, 1898; Schulze and Winterstein, 1910].

An improvement of this method was introduced by Schulze [1908], who suggested that the alcoholic solution of " raw lecithin " obtained in the manner described should be evaporated and the residue treated with acetone. What remained after acetone extraction was then dissolved in ether and lecithin precipitated from this solution by methyl alcohol.

Though no reliable method for the estimation of plant phosphatides has as yet been evolved, the results recorded by different observers indicate that the leguminosæ are relatively rich in this substance, the dried seeds containing up to 1·5 per cent. or more of phospholipin. On the other hand, cereals generally contain much less, the amount present being roughly about 0·5 per cent.

Observations on the Nature of Plant Phosphatides.

Schulze and Winterstein [1903] drew attention to the marked variability in the phosphorus percentage of different specimens of plant lecithin as found by various observers, and pointed out, that while the theoretical formula for lecithin required a phosphorus content of about 3·8 per cent., many plant lecithins contained considerably less than this amount. Similar observations applied to the nitrogen content. This variation in phosphorus percentage is well seen in the figures given :—

Observer.	Source of Lecithin.	Phosphorus Percentage.
Schulze and Likiernik [1891]	Lupines and vetches	3·68
Stoklasa [1895]	Oats (germinating)	4·23
Schulze and Frankfurt [1894]	Mushroom (Boletus edulis)	3·41
" " "	Rye and barley	*Circa* 2
Wintgen and Keller [1906]	Soya beans (brown)	2·96
" " "	" " (black)	2·51
Euler and Nordenson [1908]	Carrots	2·53 to 2·75
Anderson [1923]	Corn pollen	4·09

With the exception of Stoklasa's and Anderson's specimens, the phosphorus data are all too low for lecithin, though, in the case of lupines and vetches, the percentage approaches the theoretical figures. The obvious inference from this was either that plant lecithin differed in constitution from that obtained from animals or that it contained some impurity. Considerable light was thrown on the problem by the important discovery of Winterstein and Hiestand [1906] that plant phosphatides yielded on hydrolysis not only the usual decomposition products of lecithin, but sugar as well. The sugar content was often very large and, in some cases, amounted to over 16 per cent.; in other cases only a small amount was present, and in one product (lecithin from the seeds of *Pinus cembra*) sugar was probably absent [Schulze, 1907; 1908, 1].

It is interesting to note that the specimens of lecithin containing small amounts of phosphorus generally yielded the largest amount of carbohydrate, a result which indicated that the sugar accounted, at least to a large extent, for the low phosphorus value. Schulze [1907] showed that the presence of sugar was not the sole cause.

Observer.	Source of Phosphatide.	Percentage of P.	Percentage of Sugar.
Winterstein and Hiestand [1908] .	Wheat meal . .	1·6 to 2·5	16·65
,, ,, ,, ,, .	Avena sativa seeds .	1·96	16·81
,, ,, ,, ,, .	Lupinus albus seeds	2·7	17·9
,, ,, ,, [1907, 1908]	,, luteus ,,	3·69	1·1
,, ,, ,, ,, ,,	Vicia sativa seeds .	3·67	3·16
,, ,, ,, ,, ,,	Pinus cembra seeds.	3·60	Traces
,, ,, ,, [1908] .	Potato tubers .	1·61	6·98
,, ,, ,, ,, .	Pollen . . .	1·44	14·93

The sugars present were identified as glucose, galactose, pentose, and methyl-pentose; some of the sugar could be removed from the lecithin by repeated washing with water, but it was impossible to obtain sugar-free products by this means. Part of this sugar, at any rate, appeared to be present in firm chemical combination and not as a physical complex, for it was necessary to boil the lecithin for several hours with 5 per cent. sulphuric acid in order to split off all the carbohydrate [Hiestand, 1906; Schulze, 1907; Winterstein and Hiestand, 1907, 1908].

Zlatarov [1925] claims to have isolated from the seeds of *Cicer arietinum* L. definite compounds of a lipin with pentose and glucose respectively. These compounds are characterised by a great tendency

to undergo oxidation; when hydrolysed by heating with 2 per cent. sulphuric acid betaine was isolated as a hydrolytic product.

The presence of carbohydrates in plant phospholipins appears to be almost universal, and suggests that we are dealing here with products of the nature of so-called "jecorin," but that along with such physical complexes, bodies identical with, or similar to the animal galactolipins are of wide occurrence. According to Winterstein and Smolenski [1909] these compounds exist preformed in the plant, and are not artificial products of extraction. Various attempts at fractional separation of the different lipins found in plant extracts have been attempted and the isolation of crystalline phospholipins described [Winterstein and Smolenski, 1909; Smolenski, 1909]. Grafe and Horvat [1925] claim to have obtained from the beetroot a lipin completely free from carbohydrate. The work of Hansteen Cranner [1922] quoted by Grafe [1925] showed that when the roots and other cell tissues of certain plants were extracted with water at a low temperature, various phospholipins could be obtained, some of which were soluble and some insoluble in water. The water-soluble phospholipins obtained in this way by direct extraction with water were extremely sensitive to the action of increased temperature of light and air and of organic solvents: under the influence of these agents a change took place which rendered them insoluble in water, and which may possibly be regarded as akin to the denaturation of proteins.

Grafe and Horvat [1925] extracted finely sliced beetroot with water at 18° C., and after concentrating the dialysate at a low temperature, obtained a lipin completely soluble in water giving a clear solution. This compound was precipitated by lead acetate, and after hydrolysis gave only a weak Fehling reaction. Glycerophosphoric acid, choline and oleic and palmitic acids were obtained from it as hydrolytic products. The analyses of this water-soluble lipin were, however, made on its lead compound, since the investigators found it impossible to recover the original lipin in an unchanged condition from the lead compound. From their analytical numbers, however, they deduce a formula in which four atoms of lead are combined with one molecule of lipin; it is clear therefore that this cannot be accepted, and that the lead-free lipin must be isolated and analysed before a satisfactory formula can be deduced for it.

The possibility of obtaining a perfectly clear solution of lipin by extracting plant tissues with water at a low temperature is, however, deserving of further investigation.

That plant phosphatides tend to take up inorganic material appears from the observations of Schlagdenhauffen and Reeb [1902], and of Winterstein and Stegmann [1909].

Hydrolytic Products of Plant Phospholipins.

In general, the decomposition products obtained on hydrolysis of plant phospholipins are similar to those found in lecithin from the animal kingdom, and include fatty acids, glycerophosphoric acid and bases.

Fatty Acids of Plant Phospholipins.

As in the case of animal lecithin, little is known with certainty as to the nature of the fatty acids of plant lecithin. Schulze and Likiernik [1891] found oleic acid and a solid acid among the products of hydrolysis of a phospholipin prepared from leguminosæ seeds. The solid acid probably consisted of a mixture of palmitic and stearic acids. Similar acids were found by Shorey [1898] in sugar-cane lecithin. Njegovan [1911] also obtained from *Lupinus albus* phospholipin what appeared to be a mixture of palmitic and stearic acids: indications of the presence of unsaturated acids were also obtained. Palmitic and oleic acids were obtained by Grafe and Horvat from the soluble beet-root lipin. Levene and Rolf [1925; 1925, 1] have identified stearic, palmitic, linolic, and linolenic acids as hydrolytic products of Soya bean lecithin. So far the presence of arachidonic acid has not been demonstrated in plants, and it is a matter of considerable theoretical interest to know whether plant lipins contain the highly unsaturated acid now shown to occur in animal lecithin.

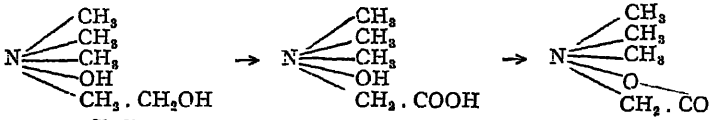
Bases of Plant Phospholipins.

The general presence of choline in plant phospholipins has been established by the work of many observers, and there is little doubt that this body is a universal constituent of these substances. Since Trier's [1911] interesting observation that amino-ethyl alcohol ("colamine") was present in the phospholipins of bean meal (*Phaseolus vulgaris*), evidence has been obtained that this base is of widespread occurrence in plant phospholipins [Trier, 1912; 1913, 2; 1913, 3].

Besides choline and "colamine" various other bases have been found from time to time in plant lipins, but so far, these are the only two products for which proof has been furnished that they actually

form part of the lipin molecule. Though other bases are no doubt sometimes present, it is possible that they occur, not as an integral part of the phosphatide molecule, but as impurities which are difficult or impossible to separate [Engeland, 1909; Schulze and Pfenniger, 1911]. Among such substances are betaine and trigonelline. Betaine is often found in plant lipins [Schulze and Pfenniger, 1911; Schulze and Trier, 1911] and has been considered by several observers to be part of the phosphatide complex [Shorey, 1898; Lippmann, 1887]. Though generally present in comparatively small amount, it sometimes occurs in considerable quantity, and in lecithin preparations isolated by Lippmann [1887] and by Zlatarov [1925] the only base found was betaine.

There seems some evidence, therefore, that betaine may occur in plants as a lipin base, a result of especial interest in view of the close relationship existing between betaine and choline, the primary alcohol group of choline being oxidised to the carboxyl group in the acid from which betaine is derived. Further investigation of this question is needed :—



Choline. Betaine.

A new base isolated by Njegovan [1911], and called by him "vidin," was, according to Trier [1912], a mixture of choline with ammonium salts.

Glycerophosphoric Acid of Plant Phospholipins.

Glycerophosphoric acid has been identified by many observers in phosphatides isolated from various plants. Zinc glycerophosphate was prepared by Schulze and Likiernik [1891] from lecithin isolated from leguminous seeds. Hiestand [1906] prepared barium glycerophosphate from plant lecithin, but was unable to decolorise his product sufficiently for polarimetric observations. The difficulty in obtaining a pure product from plant lecithin is much greater than is the case, for instance, from egg lecithin : from the latter source barium glycerophosphate can be very easily isolated in the form of a snow-white powder, while from plant lecithin, the salt is obtained with difficulty and, even then, is generally more or less highly coloured and hygroscopic [Trier, 1913, 1].

The barium compound prepared from egg lecithin by Willstätter and Lüdecke [1904] contained 43·41 per cent. of barium, and was presumably represented by the formula $C_3H_7PO_6Ba + \frac{1}{2}H_2O$. From wheat meal phospholipin, Winterstein and Hiestand [1906] obtained a barium salt with 39·5 per cent. of barium, to which these observers ascribed the formula $C_3H_7PO_6Ba + 2H_2O$; this substance differed therefore from that of Willstätter's in having $1\frac{1}{2}$ molecules more water of crystallisation.

Njegovan's [1911] barium glycerophosphate was not very different in barium content from Willstätter's products, but, unlike these preparations, was optically inactive and dissolved in water with difficulty.

Trier [1912] succeeded in obtaining an optically active *dextrorotatory* [1] barium glycerophosphate from plant lecithin, which in its barium content and solubility in water closely agreed with the dextrorotatory glycerophosphate isolated from brain by Fränkel and Dimitz [1910].

On the whole, it would seem that the glycerophosphoric acid of plant phospholipins does not differ from that of animal phospholipins.

Relation of Plant and Animal Phospholipins.

The above observations support the view that the phospholipins of plant and animal organisms are similar substances. Obviously, our present limited knowledge does not permit a definite statement on this point, but the apparent differences between animal and plant lipins, while probably largely due to incomplete investigation, depend also to some extent on incorrect interpretation of experimental results [Trier, 1913]. It appears probable that both lecithin and kephalin occur in plants [Levene and Rolf, 1925].

Relation of Phospholipin Content to Protein Content of Seeds.

According to Schulze and Likiernik [1891], Schulze, Steiger and Maxwell [1891], the amount of phospholipin present in seeds varies directly with the protein content. In seeds with a low protein content less phospholipin occurs, while, on the other hand, an increase of protein is accompanied by an increase of phospholipin. This observation was confirmed by Stoklasa [1895], and seems to be borne out in a general way by his figures, some examples of which are quoted [Czapek. 1913] :—

[1] Willstätter's glycerophosphate was lævo-rotatory.

	Lecithin Percentage.	Protein Percentage.
Triticum vulgare . . .	0·65	12·04
Zea Mais	0·28	9·12
Pisum sativum . . .	1·23	23·15
Vicia Faba	0·81	25·31
Glycine Hispida . . .	1·64	32·18
Papaver somniferum . .	0·25	19·53
Helianthus annuus . . .	0·44	14·22

Trier [1912] sought to explain such a relationship of phospholipin to protein by assuming that the amino acids of protein and the alcohol radicles of phosphatides were formed simultaneously from aldehydes according to the Cannizzaro reaction. It is by no means certain, however, that this relationship really exists, for the phospholipin estimations on which its conception depended, were carried out by estimating the phosphorus in the ether-alcohol extract, and calculating the phospholipin from this value in the usual way, a method which, as already stated, gives only rough results.

Changes in Plant Phospholipin Content during Germination and Growth.

According to Schulze and Frankfurt [1894], unripe seeds contain less phospholipin than the ripe product. This observation is not in agreement with the results of McClenahan [1913], who found the very opposite to be the case. It is probable that the variations in the phospholipin content of seeds at successive stages of ripening differ with the particular seeds investigated.

With regard to the variations of phospholipin content in germinating seeds, many experiments have been carried out. Unfortunately, the results are not always in agreement, but, on the whole, it would appear that the amount of phospholipin present is greatly influenced by the conditions under which germination takes place. When seeds are allowed to germinate in darkness, the phospholipin apparently decreases [Schulze and Steiger, 1889, 1], while in the presence of sunlight it increases [Maxwell, 1891 ; Zlatarov, 1916] :—

Observer.	Seeds Grown in Darkness.			
	Seed.	Percentage of Phosphate in Seed.	Percentage of Phosphate in Seedlings.	Time during which Germination Proceeded.
Schulze and Steiger [1889, 1]	Lupinus luteus .	2·10	·044	14 days.
Schulze [1893] . . .	Vicia sativa .	0·74	0·19	4 weeks.
Schulze and Frankfurt [1894]	Vetch seeds .	0·74 to 1·22	0·86	—
Prianischnikow [1895] .	Vicia sativa .	1·08	0·58	10 days.
Merlis [1897] . . .	Lupinus augustifolius . .	2·20	1·14	15 ,,

Similar results to the above were found by Zaleski [1902], Iwanoff [1902], and by Bernardini and Chiarulli [1910]. In the seeds of *Helianthus annuus* Frankfurt [1894] found 0·44 per cent. of phospholipin, while the etiolated plants contained 0·71 per cent.—a result contrary to the general experience of observers, and similar to that obtained when seeds develop in the presence of light:—

Observer.	Seeds Grown in Light.			
	Seed.	Percentage of Phosphate in Seed.	Percentage of Phosphate in Seedlings.	Time during which Germination Proceeded.
Maxwell [1891] .	Phaseolus vulgaris	0·933	1·841	Until radicle had protruded through testa about $\frac{3}{4}$ in.
Stoklasa [1895] .	Rape seed . .	0·45	5·22	5 days
,, ,, .	Beet seeds . .	0·45	1·78	9 ,,
,, ,, .	Buck wheat .	0·51	1·03	8 ,,
Wallerstein [1897]	Barley . .	3·06 (of total fat content)	5·04 (of total fat content)	9 ,,

Green and Jackson [1905], and Bernardini and Chiarulli [1910], obtained data supporting the above results.

It must be remembered that all these figures are based on a method of determining phospholipin which is open to criticism, and that probably on this account, they are to be looked upon as giving general indications and not definite data of the actual changes in phospholipin content, which germinating seeds undergo.

The Lipins of Yeast.

In 1879 Hoppe-Seyler prepared lecithin from yeast and showed that it contained choline and glycerophosphoric acid. Sedlmayer

[1903] isolated a lipin which he described as a dipalmityl cholin lecithin; he estimated that dry yeast contained about 2 per cent. of fat and fatty acids and 4 per cent. of crude lecithin. Koch [1903] came to the conclusion that yeast lecithin more closely resembled brain lecithin than that obtained from other sources, and recently Austin [1924] isolated both amino-ethyl alcohol and choline from the lecithin fraction. There is some reason for believing, therefore, that both kephalin and lecithin are present in yeast: Austin could, however, find no indication of sphingomyelin.

Sedlmayer observed that very little lecithin is present in old yeast: it is apparently split by some unknown enzyme during autolysis.

Such evidence as is available seems to show that the phospholipins occurring in yeast are similar to the lecithin and kephalin of animal tissues.

PLANT GALACTOLIPINS.

That bodies similar to the galactolipins of animal tissues are of widespread occurrence in plants, is indicated indirectly by various experimental results. Thus the constant presence of sugar which in many cases appears to be galactose, and the difficulty with which this galactose is split off on hydrolysis, suggest the presence of galactolipins.

Very few attempts have been made to isolate these bodies, but in one or two cases, products of the nature of galactolipins have been obtained. Trier [1913, 3] isolated a substance having the properties of a galactolipin from rice, and similar bodies have been obtained from mushrooms [Bamberger and Landsiedl, 1905; Zellner, 1911]. The isolation of galactolipins from plants should furnish a fertile field for future investigation.

CHAPTER VII.

THE FUNCTION OF LIPINS.

Lipins from the Biological Standpoint.

FROM what has already been said regarding the unsatisfactory state of our knowledge of the lipins, it follows that their exact function in the animal and vegetable economy is necessarily obscure. Their great importance in the living organism is indirectly proved by their general occurrence in every cell, but little or no direct experimental proof indicating their specific function has as yet been obtained. When we consider the obscurity in which the chemistry of the lipins has been shrouded and the fact that even now their chemical nature, in many cases, is not completely established, it is easy to understand that many of the properties and functions ascribed to these bodies are based on little more than imagination. Some years ago, when the subject of immunity was still in its earliest infancy, it was the fashion to ascribe to the action of "lipoids" many of the inexplicable phenomena encountered. Each author's interpretation of the term "lipoid" varied, and was often as difficult to understand as the phenomena he attempted to explain, until gradually the term became one of the most useful covering words in the new science. This extensive use of the word "lipoids" endowed these bodies with an artificial and one-sided importance which subsequent research has failed to substantiate, and it is now certain that the "lipoids" do not play the important rôle in the processes of immunity with which they were formerly credited. It was generally assumed that lecithin can act as an antigen in the Wassermann reaction, but from some unpublished experiments carried out by Dudgeon and MacLean it appears that this is not so. The active substance is not lecithin itself, but some other body which is difficult to separate from lecithin. This unknown substance can be separated under certain conditions, and very active solutions obtained which are practically lecithin-free. In fact, so far as can be ascertained from the more recent literature, it is questionable whether the lipins are concerned to any extent in immunity reactions. This does

not, however, indicate that these complex substances are not as important as they were formerly supposed to be ; it only shows that their particular functions are exercised in other directions. Were these bodies not essential for life, it is almost impossible to understand their invariable presence wherever the phenomena of life are manifest. That they are indispensable is obvious, but the particular part they play is at present quite unknown, despite the voluminous literature on the subject. A few of the alleged chief functions of the lipins are discussed below.

The Fate of Lecithin in the Body.

All endeavours to obtain information about the fate of lecithin in the body by administering lecithin as food and observing the results have met with little success ; nor is this to be wondered at, for lipin is split into its components by the lipase of the intestinal juice and apparently is absorbed as glycerophosphoric acid, choline and fatty acids. These experiments, therefore, cannot from their very nature really give any information as to the influence of lecithin in the body.

Beneficial results from lecithin feeding are, however, claimed by many observers, who state that it produces an increase in body weight and that it acts as a stimulating agent to normal growth [Desgrez and Zaky, 1902 ; Hatai, 1904 ; Bain, 1912]. Franchini [1907] found that the administration of lecithin was followed by a high lecithin content of liver and muscles, and a retention of both phosphorus and nitrogen after lecithin feeding was found by several workers [Stassano and Billon, 1902 ; Slowtzoff, 1906 ; Yoshimoto, 1910 ; Patta, 1912]. This retention was, however, accompanied by a diminished excretion of sulphate and hence Slowtzoff concluded that the ultimate effect was the retention of protein in the body. Brinkman and Van Dam [1920, 3] claim that lecithin fed to rabbits produces a lowered resistance to hæmolysis in the red corpuscles.

Large doses of lecithin administered to mice are stated to have produced a retardation of growth ; this is, however, so slight that it is questionable whether it can be regarded as significant [Robertson, 1916]. A slight retardation of the growth of suckling mice also followed the administration of 100 milligrams of egg lecithin per day given by mouth to the mother [Robertson and Cutler, 1916]. From the large proportion of lipin present in egg-yolk, it might be inferred that lecithin is a particularly suitable form of food for the developing animal. Experiments in which lecithin has been added to the culture

medium in which various organisms were developing have provided quite contradictory results. Since these experiments were carried out with preparations which are now known to be impure mixtures of lipins with their degradation products and other impurities, whatever the results obtained, they would throw little light on our knowledge of the pure lipins. The discrepant nature of these results is indicated by the following examples. Danilewsky [1895], for instance, found that frogs' eggs placed in water containing 0·07 per cent. lecithin gained 300 per cent. more in weight than those placed in ordinary water. Frog embryos when fed with egg lecithin have been found to increase in weight and size more rapidly than normal tadpoles [King, 1907; Johnson, 1913]. On the other hand, in the division-rate of paramœcia [Browder, 1915] and in the development of fertilised sea-urchin eggs in sea water [Goldfarb, 1910; Robertson, 1913], marked retardation of growth has followed the addition of lecithin to the culture medium.

Since lecithin is split in the alimentary canal and is not directly absorbed, we should expect to find that it is synthesised in the body. It does not, however, appear to be resynthesised after hydrolysis in the course of digestion [Eicholtz, 1924]. For a long time it was believed that the lipins could not be synthesised by the organism unless the phosphorus was supplied in an organic form. This view was disproved by the work of Gregersen [1911], who showed that the organism could maintain itself in phosphorus equilibrium when phosphates were the only phosphorus-containing material given in the food. Fingerling [1912; 1912, 1] found that ducks fed on a diet containing only inorganic phosphorus produced eggs with a normal lecithin value. The synthesis of lecithin from food containing only inorganic phosphates was therefore established, a result since confirmed by the work of Plimmer [1913] and McCollum, Halpin and Drescher [1913].

Since there is evidence that lecithin can be synthesised in the body when phosphates are the only source of phosphorus in the diet, we should not expect the inclusion or omission of lecithin from the diet to be followed by any very striking result. Many experiments have been carried out to determine the effect of feeding with a diet entirely free from lecithin. It is not, however, easy to remove lipins entirely from the diet by extraction with solvents without at the same time removing fat, sterol and other constituents. During the work which has been carried out on the recognition of the different vitamins, as each new vitamin or accessory factor has been described, suggestions

have always been made that it was of the nature of a lipin. In every case further purification of the material has shown that the lipin present was not the essential factor.

Stepp [1909, 1911, 1913] found that previous extraction with solvents such as alcohol and ether removed something from the diet which was essential for the maintenance of life. He suggested that the essential substance removed was of a lipin nature, but he could not find any known lipin which restored the normal power of the diet. Osborne and Mendel [1912] found in experiments on rats that the body weight was well maintained on a fat-free diet. McArthur and Luckett [1915] were able to eliminate lecithin, kephalin, galactolipins, cholesterol and fat from the indispensable constituents of a food for mice. The classical work of Hopkins [1912] showed that specific substances were essential for the production of growth in young animals. Milk was found to be especially active in restoring the power of growth to young animals fed on a synthetic diet; butter was also found to possess the same property [McCollum and Davis, 1913; Osborne and Mendel, 1913, 1; 1916], but the essential constituent was found to be still contained in purified butter fat which could be shown to be entirely free from lipins. In beri-beri also it was at one time claimed that lecithin produced a curative effect, but again the curative effect was found to disappear as the lipins became more highly purified [MacLean, 1912; Funk, 1911, 1912; Cooper, 1914]. It seems to be now clearly established that whatever may be the function of the lipins, it is quite distinct from that of the vitamins or accessory factors.

The Effect of the Injection of Lipin into the Blood.

Desgrez and Zaky [1902, 1] injected preparations of lecithin into the blood stream and described their effect as resulting in an increase of body weight, especially in the nervous and skeletal systems. The most noticeable result of the injection of lecithin seems, however, to be a marked increase in the number of red blood corpuscles and of the mononuclear leucocytes [Stassano and Billon, 1902; Kepinow, 1911; Bain, 1912]. This is interesting in view of the finding of Bloor, that during the absorption of fat there is a marked increase in the amount of lecithin in the red blood corpuscles. Indeed, there seems to be some evidence that lecithin plays an important part in the story of the red blood corpuscle, a point that will be again referred to. It

must, however, be pointed out that in all these earlier experiments, purified lecithin was not known and the substance injected was certainly a mixture of lecithin, and its degradation products with some kephalin and other impurities.

The Part played by Lipins in the Coagulation of the Blood.

In the phenomenon of the clotting of blood, three factors are recognised as participating in the formation of the fibrin ferment: (1) A substance, *prothrombin*, already existing in the blood; (2) the calcium salts normally present in the plasma; and (3) an active thromboplastic substance which may be furnished by the breaking down of the blood platelets or leucocytes or by an extract of various tissues. According to some investigators, this substance contained in the tissue extracts, the "cytozyme" of Bordet and Delange [1912], activates the prothrombin already existing in the plasma. Howell [1912], on the other hand, considers that the thromboplastic material of the tissues acts by neutralising antithrombin, the substance normally present in plasma, which is instrumental in preventing clotting and which has to be neutralised in order that coagulation may take place. This view is also supported by Shingu [1922].

Whatever may be the mode of action of this thromboplastic substance, there is a general agreement among investigators that lipins are concerned in producing the thromboplastic effect of the tissue extracts. Many years ago Wooldridge [1893] showed that the alcohol-ether extract of blood corpuscles had a marked effect in inducing coagulation; he therefore regarded lecithin as contributing to the activity of the tissue extracts, although he showed that lecithin prepared from egg-yolk was inactive. Although most investigators are agréed that lipins play some part in producing the thromboplastic effect of the tissue extract, some observers apparently regard the lipins as the essential active constituents [Bordet and Delange, 1912; Howell, 1911, 1912; J. McLean, 1916; Waksman, 1918], while others consider that the active substance is a compound of lipin with a specific protein, and that while both constituents have some action, the combination of both is much more effective in producing clotting [Rumpf, 1913; Mills, 1921]. Wooldridge originally showed that the active substance was precipitated by acetic acid and regained its activity on solution in dilute sodium carbonate solution, and it seems to be established that in the tissues the lipin is in combination with a globulin coagulating

at 56° to 60°, and carrying down the lipin with it in the coagulum. On extracting this precipitate with ether an active extract is obtained. Rump, [1913], however, found that lipin emulsions prepared from ox brain were far less active than tissue extracts in hastening coagulation, although serum deprived of its lipins by extraction with petroleum would only coagulate after lipins had been again added to it. This is confirmed by Mills [1921; 1921, 1], who points out that the potency of preparations of lipins is never equal to that of the tissue extract, and that if the compound of lipin and protein which occurs in the tissue extract be extracted with ether, both the lipin and protein fractions are active, but when the two fractions so obtained are mixed together the activity is greatly increased.

We owe our knowledge of the nature of the lipin constituent chiefly to Howell [1912]. He showed that this was soluble in ether and hot alcohol, but only very slightly soluble in cold alcohol, and suggested therefore that kephalin was the active agent. He also made the interesting observation that lung tissue, which is particularly rich in the thromboplastic substance, contains chiefly a lipin insoluble in cold alcohol. J. McLean, working in Howell's laboratory, confirmed and extended these observations, and clearly showed that while kephalin was active, lecithin and sphingomyelin were without effect: preparations of "cuorin" and "heparphosphatide" were also inactive. The thromboplastic activity of kephalin bears a direct relation to its degree of unsaturation; both reduction and oxidation render the preparation ineffective, and a solution of kephalin gradually loses its activity on standing. Zunz and Barre [1921; 1921, 1] have also adduced evidence in support of the view that kephalin is the active agent by showing that the "cytozymine" of Bordet and Delange contains most of its nitrogen in the amino form. It is interesting that as far as we know the fatty acid radicles of both lecithin and kephalin are identical, yet though the potency of kephalin as a thromboplastic agent appears to depend on the presence of its unsaturated radicle, the same acids are ineffective when combined in the lecithin molecule. The work on the coagulation of blood has proved especially interesting in clearly differentiating for the first time this action of kephalin from that of other lipins.

Endeavours to correlate the power of the vascular endothelium to prevent coagulation of the blood with its lipin content have proved unsuccessful [Tait and Campbell, 1914; Tait and Hewitt, 1914].

The Haemolytic Action of the Lyso Lipins.

Various authors have attributed a hæmolytic action to the lipins, but there is no evidence at all that the pure lipins possess this property. Brinkman and Van Dam [1920], for instance, found that the resistance of the red corpuscles to hæmolysis is very much increased if they are washed with physiological saline. The substance washed out is soluble in alcohol, and is considered to be of a lipin nature; the resistance of the corpuscles is again lowered if they are introduced into serum or into a solution of commercial lecithin, the substance washed out by the saline apparently being now replaced. Brinkman and Wastl [1924] consider that the power of the corpuscles to agglutinate depends on the properties of their surface layer, and especially on the size and surface charge of the corpuscles and on their surface tension when suspended in a medium. Such experiments as these, however, furnish little evidence as to the influence of the pure lipins. It is, indeed, very probable that lipins and sterol are built up into the surface layer of the corpuscle and exercise an important influence on the properties of the corpuscle which are dependent on the presence of this surface layer. The allocation, however, of the exact part attributable to each of the constituents of the layer is an exceedingly difficult problem which has yet found no solution.

Although the pure lipins do not possess hæmolyticproperties, the lysolipins are highly active. Kyes [1903; 1907] showed that when blood is hæmolysed by cobra venom, a reaction takes place between the venom and the lecithin which he described as resulting in the formation of a compound, a so-called cobralecithide. Later, Delezenne and Ledebt [1911; 1911, 1; 1912] demonstrated that the venom contained an enzyme which acts rapidly on solutions of lecithin splitting off the unsaturated fatty acid radicle. A definite crystalline compound is formed in which the saturated fatty acid radicle remains bound to the cholineglycerophosphoric acid [Delezenne and Fourneau, 1914]. This substance, lysolecithin, has powerful hæmolytic properties. Levene and Rolf [1923, 1924] succeeded in separating it into lysokephalin and lysolecithin, the venom enzyme acting on both lipins and forming similar products (see p. 38). Both the lysolipins react with cholesterol forming compounds which have no hæmolytic action; the cholesterol prevents the hæmolysing action of the lysolipins as it does that of the saponins, combining with them and forming inactive substances. This is the first instance of the isolation of a definite derivative of lecithin having

marked physiological properties. The ease with which degradation products of the lipins are formed in the tissues has been repeatedly referred to in describing the separation and purification of lecithin and kephalin (see p. 51). Our knowledge of these decomposition products is very limited, and it seems possible that their formation and their combination with other constituents may have some part in the mechanism of the normal reactions of the body.

The Role of the Lipins in Fat Metabolism.

Indications are gradually accumulating that the lipins play some part in the story of fat metabolism, but there is at present no conclusive evidence enabling us to determine their functions with certainty. This is partly due, no doubt, to the difficult nature of the experimental work involved, the marked tendency to decomposition and oxidation which is exhibited by the lipins, rendering such work of exceptional difficulty.

It has already been shown that our knowledge of the constitution of the fatty acids bound up in the lipins has recently been much advanced by the work of Levene and his colleagues, and there are good grounds for believing that several lecithins exist, each containing one radicle of saturated and one radicle of unsaturated fatty acid in the molecule (cp. p. 30). Palmitic and stearic occur as the saturated, oleic and arachidonic as the unsaturated acids; in egg-yolk linolic acid is also present. The widespread occurrence in the lipins of the highly unsaturated arachidonic acid must certainly be regarded as a fact of some significance.

Experiments carried out by McCollum, Halpin and Drescher [1912] appear to establish definitely the important fact that the degree of saturation of the fatty acids of the lipins can be influenced by the character of the diet. Two series of experiments were carried out on hens: in one set the hens were fed on normal diet, and in the other, on a diet as far as possible freed from fat and lipins. The fats and lipins of the eggs laid by hens fed with the normal diet were markedly more unsaturated than those of the eggs from the hens fed on a diet which had previously been freed from fat and lipin (see opposite page).

This observation furnishes direct evidence that the fatty acids taken as food exercise some effect on the nature of the lipin fatty acids, and indirectly supports the view that the fatty acid stored in the body may be built up into the lipins.

TABLE SHOWING INFLUENCE OF DIET ON CHARACTER OF FATTY ACIDS OF LIPINS.

	Iodine Values.					
	(*a*) Fatty Acids in Diet.			(*b*) Fatty Acids in Lipins.		
	(1)	(2)	(3)	(1)	(2)	(3)
Nearly lipin-free ration .	50·0	54·36	51·1	35·22	34·07	34·0
Ordinary ration . . .	63·2	65·5	—	63·7	63·1	—

The view, originally suggested by Leathes, that the lipins probably play some part in the desaturation of the fatty acids, has found, on the whole, little direct experimental evidence to support it. Leathes first brought forward evidence that desaturation of the fatty acids takes place in the liver [Leathes and Meyer-Wedell, 1909]. Hartley [1909] isolated arachidonic acid from the pig's liver and showed that it contained four double bonds. He showed further that in the liver an oleic acid occurred which contained a double bond between the twelfth and thirteenth carbon atoms, and which was isomeric with the ordinary oleic acid, which contains a double bond between the eighth and ninth carbon atoms. A linolic acid was also present containing two double bonds between the twelfth and thirteenth and between the eighth and ninth carbon atoms respectively, and which was isomeric with the linolic acid obtained from linseed oil. The fact that a double bond occurs in both the linolic and the oleic acids of the liver between the twelfth and thirteenth carbon atoms suggests the possibility that the liver may have the power to introduce an extra double bond in this position into both the oleic and stearic acids which occur in the storage fat of the liver. It is now generally accepted that a transformation of fatty acids to more highly unsaturated acids takes place in the liver, but it is not clear that the liver is the only organ in which this change may occur; lipins containing highly unsaturated acids occur in the heart, kidney, and brain. MacLean and Williams [1909] showed that the greater proportion of the fat extracted from the liver was present in the lipin form; indeed, the lipin fat may form as much as 84 per cent. of the total fat. Levene found that the proportion of arachidonic acid was considerably higher in the liver lipin than in the lipin prepared from egg-yolk [Levene and Rolf, 1922].

If the fatty acids were built up into lipins before their desaturation occurred, it would be expected that the highly unsaturated fatty acids would only be found in the fatty acids derived from the lipins and not

in the acids derived from the other fat present in the tissues. Kennaway and Leathes [1909] endeavoured to determine whether the presence of the more highly unsaturated acids was confined to the lipins of the liver or was distributed both in the lipin and in the non-lipin fat of the tissues. They found that the iodine value of the lipin acids was somewhat higher than that of the fatty acids isolated from the acetone-soluble fat, but the difference was not so great as might be expected if the presence of the highly unsaturated fat was confined to the lipins. Their results are not altogether conclusive, but as far as they go they seem to indicate that fatty acids more unsaturated than oleic acid are not confined to the lipins, but occur also in the other fat of the tissue. On the whole, we cannot say at present that there is any direct experimental evidence in support of the view that the fatty acids are built up into the lipin molecule prior to undergoing desaturation.

The suggestion that the lipins are concerned in the transport and mobilisation of fat for utilisation by the tissues seems to have found more general acceptance. Palmitic, stearic, and oleic acids are found in all the storage fat of the body, and we have already pointed out that there is reason to believe that more highly unsaturated fats occur in the liver. If the lipins constitute the means by which the fatty acids are transported in the body, a knowledge of the constitution of the lipins in the blood and of the variations they undergo in health and disease is obviously of importance, and this subject has been investigated especially by Terroine [1914] and by Bloor and his colleagues. These investigations have not, however, produced any very definite evidence that the lipins are concerned in the transport of the fatty acids. Bloor [1916, 1923, 1924] found that a large proportion of the unsaturated fatty acids of the blood are present as cholesteryl esters; the proportion of the fatty acids present as lipin was unexpectedly small, and their iodine value comparatively low, a result which Bloor thinks may possibly to some extent be accounted for by the particular technique employed. Bloor also found that the proportions of lipin, cholesterol and total fatty acids present in normal blood were fairly constant. During the absorption of fat from the intestine there is a great increase of fatty acids in the lymph, but only a small increase of lipin [Eckstein, 1925]; in the blood, on the other hand, Bloor [1916] found that the proportion of lipin to total fatty acid remained remarkably constant under ordinary circumstances. A marked increase of lipin took place in the blood corpuscles: this,

Bloor believes, is significant, and he considers that during the time of fat absorption the fatty acids are converted to lipin in the corpuscles. The variations in the proportion of cholesterol present were, however, small and insignificant, but there was, at the same time, a marked increase in the amount of cholesteryl esters in the corpuscles. In cases of pronounced lipæmia, the cholesterol increased more than the lipin. The results of different observers are not in complete agreement, for Terroine [1914] found that the ratio $\frac{\text{cholesterol}}{\text{total fatty acids}}$, termed the lipæmic coefficient, showed little variation during the period of fat absorption.

On the whole, we may say that when we consider the experimental evidence from the analyses of blood during fat absorption, both cholesterol and lipin seem to be concerned in the transport of fat. The increase both of lipin and cholesteryl esters in the blood during fat absorption is an observation of much interest; when this is considered in conjunction with the fact that in the blood plasma the more unsaturated fatty acids seem to be chiefly associated with the cholesterol as esters, it must be confessed that the actual evidence for the transport of fatty acids as cholesteryl esters is as strong as that for the transport of fat in the state of lipin.

One piece of evidence has been brought forward by Meigs, Blatherwick and Carey [1919] which is extremely suggestive: the conclusions to be drawn from it are so important that it is very desirable that these experiments should be repeated and confirmed. These authors find that the lipin phosphorus is diminished and the inorganic phosphorus increased in the blood of the mammary vein when compared with the blood of the portal vein of cows with actively lactating mammary glands: a similar difference was not observed in cows which were not actively lactating. The diminution in lipin phosphorus was sufficient to allow for the whole of the milk fat secreted by the gland being derived from the fatty acids split off from the lipin which had disappeared. If this fact can be conclusively established, two results may be deduced: (1) The lipins are the agents by which the fatty acids are conveyed to the tissues; (2) the whole series of saturated fatty acids occurring in milk containing the even numbers of carbon atoms from 4 to 20 are derived from the lipin acids, i.e. from palmitic, stearic, oleic, and arachidonic acids. If this be confirmed the process of oxidation, and also that of saturation, must simultaneously be

taking place in the mammary gland. It is certainly of interest in this connexion that arachidic acid, the saturated acid with 20 carbon atoms, is found in milk, and butyric acid with 4 carbon atoms is the lowest acid present. Another instance of the splitting off of fatty acids from lipins is furnished in the development of the chick from the egg; during this period a marked change in the distribution of the lipins takes place. In the egg as much as 65 per cent. of the total phosphorus is present in the lipin form: in the chick only 20 per cent. is so combined [Plimmer and Scott, 1909; Eaves, 1910]. The evidence does not, however, show the further fate of the lipin: the fatty acids separated from the phosphoric radicle may be stored as fat in the chick, or, on the other hand, may be utilised for oxidation or in some other manner.

Rôle of the Lipins in bringing about Oxidation of the Fatty Acids.

It has been suggested that desaturation of the fatty acids is a preliminary to further oxidation and that after desaturation the long chains of fatty acids are broken into smaller molecules, cleavage taking place at the double bonds [Leathes and Raper, 1925, p. 194]. We know that under certain circumstances the unsaturated radicle is very easily split off from the lipin molecule, leaving the saturated fatty acid radicle in combination with the remainder of the molecule: this may be brought about, for instance, by the action of cobra venom, but we have no direct evidence that this change is connected with the oxidation of the acid. It might perhaps be expected that if the breaking down of the highly unsaturated fatty acids took place while the acids are combined in the lipin molecules, lipins might be found containing acids with a less number of carbon atoms than those originally present in the molecule, such as might be formed as intermediate stages on partial oxidation of the acids. It is this entire absence of intermediate oxidation products that makes the story of fat metabolism so perplexing. On the whole, the evidence available is in favour of the view that the fatty acids are oxidised at the β-carbon atom; the process, however, takes place so smoothly and so completely that only the final stage of oxidation of the long fatty chain can be identified. Between the chains containing 16 or 18 carbon atoms and acetoacetic acid, no intermediate product is known with certainty.

Wesson [1925] brought forward some evidence in favour of the view that arachidonic acid is an intermediate product between the acids of the storage fat and acetoacetic acid. He estimated the total amount of arachidonic acid occurring in the tissues of rats, and found that in fasting rats, when the store of glycogen present is exhausted, the amount of this acid rises, especially in the liver. Wesson infers that the arachidonic acid is formed from the storage fat, which is still available, an inference supported by the fact that the increase of this acid corresponds with the appearance of a positive ketone reaction in the urine. It is possible, therefore, that this acid may occur as an intermediate product, but further evidence for this view is necessary.

The present position seems to be that there is convincing evidence for the view that β-oxidation of the fatty acids occurs in the body [Knoop, 1905]; at the same time, it is possible that this is not the only method by which the oxidation of the fatty acids is brought about, and the highly unsaturated acids present in the lipins may also undergo cleavage into smaller molecules, oxidation at the same time taking place.

It is interesting that a study of the oxidation products of linolenic acid in the laboratory at 100° [Coffey, 1921] has shown that acetic acid and carbon-dioxide are among the products of its oxidation. The structure $R . CH : CH . CH_2 . CH : CH . CH_2CH : CH . R'$ which occurs in linolenic acid appears to break up into the products $R . COOH + 2CH_2(COOH)_2 + R' . COOH$, the malonic acid $CH_2(COOH)_2$ at once breaking up into acetic acid and carbon-dioxide. At present we have no evidence that such a process takes place in the body. All workers on lipins know that great difficulty is encountered in purifying the fatty acids derived from them, because of their great susceptibility to oxidation. Thunberg [1910] showed that in the presence of a trace of iron, preparations of lecithin are extraordinarily susceptible to oxidation, the original slow absorption of oxygen by the purer lecithin preparations being enormously increased by the addition of 1/1000 molecule of iron salt. Linolenic acid behaves similarly to the lecithin preparation. According to Glikin [1908, 1909] the molecule of lecithin always contains iron, and it may be in part due to this that such great difficulties are experienced in preserving the fatty acids contained in it from oxidation. It is certain that the fatty acid chains present in lipins absorb oxygen with great avidity, but we have already pointed out that there is no direct evidence that the acids are broken down into smaller molecules by

oxidation at double the bonds, or, indeed, that the acids are oxidised only while they are combined in the lipin molecules. Meyerhof [1924], indeed, suggests that the animal body makes fats and carbo hydrate accessible to oxidation by combining them with phosphoric acid, but that protein can only burn in cells after it has been split up into amino acids; although this is an interesting speculation, as far as the fats are concerned it lacks experimental basis. Recent work has shown the importance of certain sulphur acids, glutathione [Hopkins, 1921, 1922, 1925] and thioglycollic acids [Meyerhof, 1923] as promoters of oxidation in the tissues. Meyerhof found that the transfer of oxygen to dried muscle in the presence of a sulphydryl compound ceased under the conditions of his experiment if the muscle were thoroughly extracted with alcohol and ether; the presence of the lipoid constituents of muscle was necessary in order that the oxygen might be taken up. Linolenic acid was as effective as lecithin, so that this property seems to belong rather to the unsaturated acid radicle than to the combination of this radicle in the lipin molecule, for linolenic acid is oxidised as effectively by means of the sulphydryl mechanism as lecithin itself. It does not, therefore, appear from the results so far available that the building up of the unsaturated fatty acids into the lipin molecule is a necessary preliminary to their oxidation.

It is obvious that the results so far recorded do not give us any very clear indication of the specific functions of the lipins. There is some reason to believe that by their agency fats are transported to the tissues and are there utilised, and there is definite evidence that the lipins or their degradation products may play an important part in producing certain pathological phenomena such as the coagulation and hæmolysis of the blood.

The constant presence of the lipins in every cell and their retention even in conditions of extreme emaciation make it certain that they are essential for maintaining the vital processes of the cell.

Mayer and Schaffer [1913; 1913, I; 1914] examined the various tissues and found that the proportion of lipoid in most organs is comparatively constant, and is unchanged even after prolonged starvation. The liver is an exception to this rule only so far as it contains storage fat, which disappears in starvation, leaving a tissue of comparatively constant composition. The proportion of lipoid phosphorus is constant for each organ in different individuals of the same species, but varies from tissue to tissue. It appears possible that the specific

character of an organ may be conditioned as much by the proportion of its constituents as by their specific character.

The constant association of cholesterol, fat, and lipin in every tissue cannot be regarded as accidental: Mayer suggests that the proportion of cholesterol to fatty acid determines the proportion of water taken up by the cell, the water content of a tissue increasing with the cholesterol content.

In many ways the action of the cholesterol appears to be definitely antagonistic to that of lecithin, so that a certain balance of these substances may be a necessary part of the cell mechanism. The antagonistic effect of cholesterol to the hæmolysing action of lysolecithin is an instance of this. Again, cholesterol is said to diminish the phagocytic index, but its power to do so is reduced by the presence of lecithin [Stuber, 1913]. [See also Brinkman and Van Dam, 1920, 2.]

The compound formed from cholesterol and lysolecithin is in some ways particularly interesting. Delezenne and Ledebt [1911] showed, for instance, that if two molecules of cholesterol are dissolved in chloroform and added to one molecular proportion of lysolecithin dissolved in alcohol, and the solvent then evaporated, the residue forms an emulsion gradually depositing cholesterol. If this residue is now extracted with ether, one molecular proportion of cholesterol remains bound to the lysolecithin, but if the residue be first treated with alcohol, the whole of the cholesterol is dissolved out by the ether. It is well known that the lipoid matter of the tissue cannot be completely extracted by ether alone; preliminary treatment with alcohol is necessary in order that the fatty matter may be removed by ether. It is possible that in the tissues, combinations such as that of cholesterol with lysolecithin may occur which must first be broken up before they can be dissolved by the ether.

The Relation of the Lipins to the Cell Membrane.

During the present century it has been generally accepted that lipoids [lipins, fat, cholesterol) enter into the structure of the cell membranes, and hence play an important part in regulating the passage of substance to and from the cell. Overton [1901] postulated that every living cell is limited by a semipermeable membrane which consists essentially of lipoids and which is disintegrated at the death of the cell. This membrane was considered impermeable to salts; it regulated the passage of substances to and from the cell.

Overton suggested that a consideration of the distribution of an organic substance between oil and water would throw light on the ease with which the substance would pass into the cell. With Meyer, he determined the narcotic effect on tadpoles of a large number of substances, and ascertained the smallest concentration of the narcotic which would produce narcosis. There was a striking parallelism between the numbers obtained in these experiments and the partial coefficients of distribution of the same substance between oil and water. If we consider for instance the homologous series of fatty alcohols, the higher alcohols are very much more soluble in oil and enormously less soluble in water, than the lower members of the series, and in accordance with this we find that a very much smaller concentration of the higher alcohols is sufficient to produce narcosis. Some of Overton's figures are quoted below :—

Alcohol.	Partition Coefficient Oil-water.	Critical Molecular Concentration to produce Narcosis.
Methyl . . .	2 : 00	0·62
Ethyl . . .	1 : 30	0·31
Propyl . . .	1 : 8	0·11
Isobutyl . . .	: 12	0·045
Isoamyl . . .	: 2	0·023
Heptyl . . .	: 0·15	——
Octyl . . .	: 0·05	0·0004

Similar results hold for the series of ketones.

The Meyer-Overton theory has, however, found many critics; Bang [1907] pointed out certain objections, as, for instance, that the reaction period between the paralysis of the spinal cord and of the medulia oblongata varied widely with different narcotics, and suggested that the narcotic must react chemically with the lipin membrane. On Overton's theory the strength of a narcotic would be proportional to the readiness with which it entered the lipin membrane, but a subsequent chemical action between the narcotic and the lipin or other constituent might of course take place. Loewe [1912] examined the behaviour of cells placed in solutions of dyes, and found that the dyes which penetrate the cell are not really soluble in lipoids. The proportion of the dye taken up does not vary with the concentration of the solution, and Loewe considered that the phenomena were best explained by absorption. Warburg [1911, 1912] found that the absorption of oxygen by the erythrocytes of birds took place equally when the cells were hæmolysed as long as the nuclei were intact; he found

that when the red blood corpuscles were put into solutions of narcotics, their oxygen consumption was diminished. The molecular concentration of narcotic sufficient to stop respiration followed the same law as that shown by Overton to hold for the narcosis of the tadpoles. If the narcotic divided itself between the water and the lipin phase according to its partition coefficient, a very low concentration of the higher alcohols in the external aqueous solution would produce a high concentration of the alcohol in the lipin phase. Warburg showed that in the case of cell respiration the increased concentration of the narcotic in the lipin phase did not furnish an adequate explanation of the effect observed. He found, however, when dealing with the respiration of the erythrocytes that the amount of the narcotic (thymol or the higher fatty alcohols) combined with the stromata of the cell was not noticeably decreased if the stromata were completely freed from lipoids by extracting them with alcohol and ether [Warburg and Usui, 1912], and argued that the phenomenon depended therefore only on adsorption on the solid parts of the cell.

An interesting series of experiments was carried out by Vernon [1912, 1913, 1914] which aimed at showing the dependence of the action of tissue oxidases on the cell lipoids, and in thus differentiating them from nearly all other ferments. He investigated the production of indophenol blue by the action of the oxidase of the kidney on a solution containing naphthol and *o*-phenylenediamine, and found that if the tissue was first treated with an organic solvent at certain concentrations, the oxidase action was rapidly destroyed. The effects of a large number of organic solvents were investigated and were found to be proportional to the molecular weight and independent of the homologous series to which the solvent belonged. The concentrations of alcohols and ketones necessary to destroy 50 per cent. of the oxidase activity in Vernon's experiments were relatively twenty and twelve times as great as those necessary to produce narcosis in tadpoles. Vernon concluded that the effect of the oxidase was dependent on the lipoids, perhaps on the lipoid membrane which held together the tissue-oxygenase and peroxidase and made possible their mutual enzymatic activity. Czapek [1910] studied the effects of organic solvents on the exosmosis of tannin from vegetable cells and ascribed their action to surface tension phenomena; Vernon [1913] gave to Czapek's results a similar interpretation to his own, and suggested that they were also conditioned by the presence of a lipoid membrane. Somewhat similar experiments have been carried out by Palladin and

Stanewitsch [1910] on the respiration of plants. They treated wheat embryos with organic solvents and then soaked them for a short time in water, estimating the amounts of carbon-dioxide evolved during definite intervals. The respiration energy was lowest after treatment with those solvents which extracted most lipoid. There seems still to be good evidence of the importance of the cell surface in its relation to many reactions, and although the Meyer-Overton theory of a lipoid cell membrane acting solely in virtue of its solvent power for narcotics is not tenable, it is still probable that the lipins are essential constituents of the structure of the cell membranes.

Our knowledge of the structure of the surfaces separating immiscible liquids has been enlarged especially by the work of Hardy, of Langmuir [1917] and more recently of Adam [1922]. We know that when a very small amount of fatty acid is placed on a surface of water it spreads in a thin film on the surface of the water; at the surface of contact of the two liquids there is a definite arrangement of the molecules of fatty acid, the carboxyl groups being attracted to the water and there held in position, and the molecules of fatty acid being ranged side by side in an orderly manner, with their long paraffin chains pointing away from the water. The paraffin chains also exert attraction on each other, so that a coherent film is formed.

Adam has succeeded in obtaining films of the thickness of one molecule; he has measured the dimensions of the molecules in the films and has shown that when the molecules of such a substance are orientated in this manner, its physical properties are profoundly effected. In this film state, at a temperature of 38°, the palmitic acid behaves as a liquid and forms what is known as an expanded film; when it is subjected to high pressure it apparently solidifies, the molecules pack more closely together and the area occupied by each fatty acid chain diminishes. In the expanded state the molecule of palmitic acid occupies an area of 42 sq. A° (A = 10^{-8} cm.), but under compression it is reduced to an area of 21 sq. A°. Oleic acid behaves under similar conditions only as a liquid and forms only an "expanded" film. Leathes [1923] has applied Adam's methods to the study of the behaviour of lecithin, and has found that it forms films on a surface of water having much the same characteristics as those described above for the fatty acids. Like palmitic and oleic acids, lecithin forms films only one molecule in thickness; the area occupied by each fatty acid chain in the lecithin molecule is greater than that occupied by the palmitic acid molecule. Under similar conditions, the area

occupied by each of the two fatty acid chains in lecithin was 56 sq. A°, instead of the 42 sq. A° occupied by palmitic acid. Like oleic acid, the lecithin film is not condensed by compression. We know, however, that part of the acid present in lecithin is the highly unsaturated acid, arachidonic acid; before deductions can safely be drawn as to the influence of the cholyl-phosphoric group in such a molecule the behaviour of arachidonic acid must be studied. Dihydrolecithin similarly examined gave a condensed film similar to that of palmitic acid, but the fatty acid chains occupied a larger area than do the chains of palmitic acid (28 : 21), a result attributed by Leathes to the influence of the cholyl-phosphoric group in hindering close packing. The addition of cholesterol to fatty acid or to lecithin has the effect of making the fatty acid chains pack more closely together than in the absence of the cholesterol.

A curious property exhibited by lecithin is its power to spread out into so-called myelin forms first described by Virchow, and subsequently investigated by Leathes [1925]. If a streak of lecithin is made on a glass slide and viewed under a microscope, it appears to grow out into a large number of budding protrusions, the so-called myelin forms. As large a surface of contact as possible seems to be formed between the lecithin and the water. This behaviour of lecithin is in marked contrast to the behaviour of a fatty acid or glyceride for a drop of oil placed in contact with water remains spherical, the surface of contact being the smallest possible. The substitution of the cholyl-phosphoric group for the third fatty acid chain has profoundly modified the surface tension of the substance. Leathes regards these myelin forms as due to two factors, surface growth and localised inhibition of water; the property is in some way associated with the presence of the unsaturated fatty acid in the molecule, for it is not shown by the dihydrolecithin.

In the cell we do not deal with mixtures of water and lecithin alone, and the properties of such a mixture are profoundly influenced by the presence of other substances. If we consider, for instance, the interfacial tension between oil and water, we find that in an emulsion of olive oil and water it is markedly influenced by the presence of either cholesterol or lecithin: the addition of lecithin favours an emulsion in which particles of oil are dispersed through a continuous aqueous phase, whereas the addition of cholesterol favours an emulsion in which the oil is the continuous phase through which the particles of water are dispersed [Corran and MacLewis, 1924]. Clowes [1918] has

shown that the ions of sodium and calcium produce a similar phase inversion on an emulsion of a fatty phase and an aqueous solution of protein.

So far, the attempts which have been made to apply what has been learnt of these phenomena to the processes of the living cell has not made great progress, for we are there concerned with a complicated mixture of varying composition, the constituents of which are so labile that changes in them are probably produced by our methods of investigation. We may measure the amount of lipoid matter in the red blood corpuscle and estimate the area of its molecules [Gorter and Greudel, 1925], but even if we know that the quantity of lipin present is sufficient to form a layer two molecules deep over the surface of the corpuscle, it does not tell us that such a film exists. We have given above some of the criticisms which made it necessary to reject the simple conception of Overton of a lipoid membrane acting only in virtue of its solvent power. It is not to the properties of the lipins alone that we must look for our interpretation of the properties of the cell membrane. Fat, sterol, esters, lipins, electrolytes, proteins and other substances, may all play their part, and it is to the interplay of them all that we must look for any adequate interpretation of the phenomena of the living cell. The reader is referred to the Monograph on Fats (Leathes and Raper) for an interesting discussion of this subject.

It is probable also that the electric potential differences in the living cell may play an important part. Loeb and Beutner [1913, 1914] bring forward interesting evidence in support of the view that the bioelectric differences of potential observed when living cells are put into solutions of electrolytes are due to the presence of lipins in the cell membrane. If a plant leaf or a piece of apple is put into solutions of potassium chloride of varying concentrations the differences of electric potential on the surface of the cells can be measured. If lecithin is dissolved in a solution of a solvent such as guaiacol and placed in contact with similar solutions of the electrolyte, corresponding differences of electric potential are found at the surface of the solutions. Solutions of protein or cholesterol brought into contact with the electrolyte do not show similar differences, but the lipins resemble most closely in this particular the behaviour of the living cell. Similar differences of electric potential are also observed when muscle cells are placed in solutions of electrolytes. With an ordered arrangement of molecules at the cell surface we should expect that electric charges

would be produced. Quastel [1926] has recently brought forward an interesting theory which regards the electric charges on the cell surface as being concerned in the activation of the molecules taking part in the reactions of the cell; this hypothesis demands an unequal distribution of electric potential on the cell surface, and postulates a cell-membrane of complicated structure.

On the whole, such evidence as we possess supports the view that the lipins play an important part in the structure of the cell membrane, but it is not yet possible to dissociate the lipins from the other cell constituents, and attribute to them alone any specific properties associated with the cell.

BIBLIOGRAPHY.

ACTIEN GESELLSCHAFT FÜR ANILIN FABRIKATION [1905]. *Verfahrung zur Darstellung von Bromlecithin.*
D.R.P., 156110.

ADAM, N. K. [1922]. *The Properties and Molecular Structure of Thin Films.* Part II., *Condensed Films.* Part III., *Expanded Films.*
Proc. Roy. Soc. A., **101**, 452, 516.

ADRIAN ET TRILLAT, M. M. [1898]. *Étude de la réaction de l'acide phosphorique sur la glycérine.*
J. Pharm. Chim. (VI), **7**, 226; Chem. Centr., I, **131**, 214.

ALTSCHUL, J. [1912]. *Ueber "Agfa" Lecithin.*
Biochem. Zeitsch., 44, 505.

ANDERSON, R. J. [1923]. *Composition of Corn Pollen.* II. *Concerning Certain Lipoids, a Hydrocarbon and Phytosterol occurring in the Pollen of White Flint Corn.*
J. Biol. Chem., 1923, **55**, 611.

ARGIRIS, A. [1908]. *Untersuchungen ueber Vögel-und Fischgehirne.*
Zeitsch. physiol. Chem., **57**, 288.

AUSTIN, W. C. [1924]. *Phospholipins in Yeast.*
J. Biol. Chem., **59**, Proc. LII.

BAEYER, A., UND LIEBREICH, O. [1867]. *Das Protagon ein Glycosid.*
Virchow's Archiv, **39**, 183.

BAILLY, O. [1915]. *Sur la constitution de l'acide glycérophosphorique de la lécithine.*
Compt. rend., **160**, 395.

BAILLY, O. [1915, 1]. *Synthèse de l'acide α-glycérophosphorique.*
Compt. rend., **160**, 663.

BAILLY, O. [1919]. *Sur la constitution des acides glycérophosphoriques.*
Bull. Soc. Chim. Biol., **1**, 152.

BAILLY, O. [1921]. *Sur l'action de l'épichlorhydrine sur le phosphate monoacide de sodium en solution aqueuse et sur la stabilité d'un diéther monoglycéro-monophosphorique.*
Compt. rend., **172**, 689.

BAIN, W. [1912]. *Pharmacology and Therapeutics of Lecithin and Phytin.*
Lancet, 1912, i., 918.

BALDI, D. [1887]. *Einige Beobachtungen über die Verbreitung des Jecorins im thierischen Organismus.*
Arch. f. Anat. u. Physiol. (Physiol. Abt.), Suppt., 100.

BAMBERGER, M., UND LANDSIEDL, A. [1905]. *Beiträge zur Chemie der Sklerodermen.* I. *Lycoperdon Bonista.*
Monats. Chem., **26**, 1109.

BANG, I. [1907]. *Biochemie der Zell-lipoide.*
Ergebnisse der Physiol., **6**, 131.

BANG, I. [1911]. *Chemie und Biochemie der Lipoide.*
(J. F. Bergmann, Wiesbaden.)

BANG, I., AND FORSMANN, J. [1906]. *Untersuchungen über die Hämolysinbildung.*
Beiträge zur Chem. Physiol. und Path., **8**, 238.

BARBIERI, N. A. [1910]. *Sur la non-existence des lécithines libres ou combinées dans le jaune d'oeuf.*
Compt. rend., **151**, 405.

BARBIERI, N. A. [1912]. *Sur la non-existence des lécithines libres ou combinées dans le jaune d'oeuf et dans les structures biologiques.*
Compt. rend., **155**, 312.

BARGER, G. [1914]. *The Simple Natural Bases.*
(Longmans, Green & Co.)

BASKOFF, A. [1908]. *Ueber das Jecorin und andere lecithinartige Produkte der Pferdleber.*
Zeitsch. physiol. Chem., **57**, 395.

BASKOFF, A. [1909]. *Ueber Lecithinglykose im Vergleich zum Jecorin der Pferdleber.*
Zeitsch. physiol. Chem., **61**, 426.

BASKOFF, A. [1909, 1]. *Ueber Lecithin und Jecorin der Leber normaler und mit Alkohol vergiftiter Hunde.*
Zeitsch. physiol. Chem., **62**, 162.

BAUMANN, A. [1913]. *Ueber den stickstoffhaltigen Bestandteile des Kephalins.*
Biochem. Zeitsch., **54**, 30.

BAUMSTARK, F. [1885]. *Ueber eine neue Methode das Gehirn chemisch zu erforschen und deren bisherige Ergebnisse.*
Zeitsch. physiol. Chem., **9**, 145.

BELL, R. D., AND DOISY, E. A. [1920]. *Rapid colorimetric methods for the determination of phosphorus in urine and blood.*
J. Biol. Chem., **44**, 55.

BEREZELLER, L. [1914]. *Stalagmometrische Studien an Krystalloiden und Kolloiden Lösungen. Über die Einwirkung einiger Narkotica auf Lecithinlösungen.*
Biochem. Zeitsch., **66**, 225.

BERGELL, P. [1900]. *Darstellung des Lecithins.*
Ber., **33**, 2584.

BERGELL, P. [1901]. *Ueber die Spaltung des Lecithins durch den bei völlstandigen Darmverschluss abgesonderten Darmsaft.*
Centr. f. allg. Path. u. Path. Anat., **12**, 633.

BERLIN, E. [1912]. *Homocholin und Neosin.*
Zeitsch. f. Biol., **57**, 1.

BERNARD, L., BIGART UND LABBÉ, H. [1903]. *Sur la sécrétion de lécithine dans les capsules surrénales.*
Compt. rend. Soc. Biol., **55**, 120.

BERNARDINI, L., UND CHIARULLI, G. [1910]. *Lecithin und Lecithide im keimen den Samen.*
Bied. Zentr., **39**, 594.

BERNAZKY, S. S [1908]. *Das Lecithin des Knochenmarks normaler und immunissiérten Thiere.*
Biochem. Zentralbl., **7**, 827.

BERTHELOT, M. [1854]. *Mémoire sur les combinaisons de la glycérine avec les acides et sur la synthèse des principes immédiats des graisses des animaux.*
Ann. de Chim. et de Phys. (3), **41**, 216.

BETHE, A. [1902]. *Ueber einige Educte des Pferdegehirns.*
Arch. f. exp. Path. u. Pharm., **48**, 73.

BEYER, A. [1871]. *Einige Bestandtheile des gelben Lupinensamen.*
Landw. Versuchstat., **14**, 161.

BIBRA, VON [1854]. *Vergleichende Untersuchungen über das Gehirn des Menschen und der Wirbelthiere.*
(Mannheim, 1854.)

BIENENFELD, B. [1912]. *Beitrag zur Kenntniss des Lipoidgehaltes der Placenta.*
Biochem. Zeitsch., **43**, 245.

BING, H. J. [1898]. *Ueber das Jecorin.*
Zentr. f. Physiol., **12**, 209.

BING, H. J. [1899]. *Untersuchungen über die reducirenden Substanzen im Blute.*
Skand. Arch. f. Physiol., **9**, 336.

BING, H. J. [1901]. *Ueber Lecithinverbindungen.*
Skand. Arch. f. Physiol., **11**, 166.

BITTO, VON BÉLA [1894]. *Ueber die Bestimmung des Lecithingehaltes der Pflanzenbestandtheile.*
Zeitsch. physiol. Chem., **19**, 488.

BITTO, VON BÉLA [1896]. *Neuere Untersuchungen über die chemische Zusammensetzung der roten paprikaschote.*
Landw. Versuchsstat., **46**, 309.

BLOOR, W. R. [1912]. *Carbohydrate Esters of the Higher Fatty Acids. Mannite Ester of Stearic Acid.*
J. Biol. Chem., **11**, 141.

BLOOR, W. R. [1912, 1]. *Carbohydrate Esters of the Higher Fatty Acids. Mannite Esters of Lauric Acid.*
J. Biol. Chem., **11**, 421.

BLOOR, W. R. [1915]. *A Method for the Determination of "Lecithin" in Small Amounts of Blood.*
J. Biol. Chem., **22**, 133.

BLOOR, W. R. [1915, 1]. *Studies on Blood Fat.* II. *Fat Absorption and the Blood Lipoids.*
J. Biol. Chem., **23**, 317.

BLOOR, W. R. [1916]. *Fat Assimilation.*
J. Biol. Chem., **24**, 447.

BLOOR, W. R. [1916, 1]. *The Distribution of the Lipoids ("Fat") in Human Blood.*
J. Biol. Chem., **25**, 577.

BLOOR, W. R., JOSLIN, E. P., AND HORNOR, A. A. [1916, 2]. *The Lipoids ("Fat") of the Blood in Diabetes.*
J. Biol. Chem., **26**, 417.

BLOOR, W. R. [1918]. *Methods for the Determination of Phosphoric Acid in Small Amounts of Blood.*
J. Biol. Chem., **36**, 33.

BLOOR, W. R. [1918, 1]. *The Distribution of Phosphoric Acid in Normal Human Blood.*
J. Biol. Chem., **36**, 48.

BLOOR, W. R. [1923]. *The Fatty Acids of Blood Plasma.*
J. Biol. Chem., **56**, 711.

BLOOR, W. R. [1924]. *The Forms of Combination of the Unsaturated Acid in Blood Plasma.*
J. Biol. Chem., **59**, Proc. XXIV.

BOKAY, A. [1877]. *Ueber die Verdaulichkeit des Nucleins und Lecithins.*
Zeitsch. physiol. Chem., **1**, 157.

BOLLE, A. [1910]. *Über den Lecithingehalt des Knochenmarks von Mensch und Haustieren.*
Biochem. Zeitsch., **24**, 179.

BORDAS, F., ET RACZKOWSKI, SIG. DE [1902]. *Sur le dosage de la lécithine dans le lait.*
Compt. rend., **134**, 1592.

BORDET ET DELANGE [1912].
Annales de l'Institut Pasteur, **26**, 657, 737.

BOURGOIN [1874]. *Note sur la purification de la Cérébrine.*
Bull. soc. chim., Nouv. Ser., **21**, 482.

BRIGGS, A. P. [1922]. *A Modification of the Bell-Doisy Phosphate Method.*
J. Biol. Chem., **53**, 13.

BRIGL, P. [1915]. *Synthetische Beiträge zur kenntniss der Cerebronsäure.*
Zeitsch. physiol. Chem., **95**, 161.

BRIGL, P., AND FUCHS, E. [1922]. *Ueber die Lignocerinsäure und ihre Derivate.*
Zeitsch. f. physiol. Chem., **119**, 280.

BRINKMAN, R. [1922]. *Experimental Anæmia by Injection of Lecithin.*
Ned. Tijd. Geneesk., **66**, 1, 2462. *Physiol. Abs.*, **8**, 269.

BRINKMAN, I. R., AND VAN DAM, E. [1920]. *Studien zur Biochemie der Phosphatide und Sterine.*
I. *Einleitung.*
Biochem. Zeitsch., **108**, 35.
II. *Die Bedeutung des Cholesterins für die physikalisch-chemischen Eigenschaften der Zelloberfläche.*
Biochem. Zeitsch.. **108**, 52.
III. *Ueber die Bedeutung des funktionellen Antagonismus von Phosphatiden und Cholesterin.*
Biochem. Zeitsch., **108**, 61.

BRINKMAN, I. R., AND WASTL, H. [1921]. IV. *Ueber die Bedeutung des Verhältnisses Cholesterin Lecithin der Körperchen-oberfläche für die Stäbilität die Blüthörperchen-suspension und für die natürliche Hämolyse.*
Biochem. Zeitsch., 124, 25.

BRODRICH-PITTARD, N. A. [1914]. *Zur Methodik der Lecithinbestimmung in Milch.*
Biochem. Zeitsch., 67, 382.

BROWDER, A. [1915]. *The Effect of Lecithin and Cholesterol upon the Division Rate of Paramecium.*
Univ. California Pub., Physiol., V, 1.

BROWN, H. T., AND MORRIS, G. H. [1890]. *Note on the Identity of Cerebrose and Galactose.*
J. Chem. Soc., 57, 57.

BÜRGER, M., AND BEUMER, H. [1913]. *Über die Phosphatide der Erythrocytenstromata bei Hammel und Menschen.*
Biochem. Zeitsch., 56, 446.

BUROW, R. [1900]. *Der Lecithingehalt der Milch und seine Abhängigkeit vom relativen Hirngewichte des Säuglings.*
Zeitsch. physiol. Chem., 30, 495.

BUROW, R. [1910]. *Über das Vorkommen eisenhaltiger Lipoide in der Milz.*
Biochem. Zeitsch., 25, 165.

CAHN, A. [1881]. *Zur physiologischen und pathologischen Chemie des Auges.*
Zeitsch. physiol. Chem., 5, 213.

CALUGAREANU, D. [1910]. *Wirkung des Chloroforms auf Lipoidsuspensionen.*
Biochem. Zeitsch., 29, 96.

CARRÉ, P. [1904]. *Sur les éthers phosphoriques de la glycérine.*
Compt. rend., 138, 47.

CARRÉ, P. [1912]. *Sur la constitution de l'acide glycérophosphorique obtenu par éthérification de la glycérine au moyen de l'acide phosphorique ou du phosphate monosodique.*
Compt. rend., 154, 220.

CARRÉ, P. [1912, 1]. *Sur l'acide Glycérotriphosphorique de Contardi.*
Compt. rend., 155, 1520.

CASANOVA, C. [1911]. *Ueber Eierlecithin, ueber eine charakteristische Farbreaktion und eine häufige Verfälschung desselber.*
Chem. Centr., II, 231.

CENTANNI, E. [1910]. *Über den befördernden Einfluss der Lipoide auf die Wirkung der Leberdiastase.*
Biochem. Zeitsch., 29, 389.

CHEVALIER, J. [1886]. *Chemische Untersuchungen der Nervensubstanz.*
Zeitsch. physiol. Chem., 10, 97.

CHRISTEN, TH. [1905]. *Untersuchung über Ascites und Liquor pericardii.*
Biochem. Zentr., 4, 21.

CIACCIO, C. [1915]. *Untersuchungen über die auto-oxydation der Lipoidstoffe und Beitrag zur Kenntniss einiger Pigmente (Chromolipoide) und Pigmentkomplexe.*
Biochem. Zeitsch., 69, 313.

CLOWES, G. H. A. [1918]. *On the Action exerted by Antagonistic Electrolytes on the Electrical Resistance and Permeability of Emulsion Membranes.*
Proc. Soc. f. Exp. Biol. and Med., 15, 108.

COFFEY, S. [1921]. *Linolenic and Linolic Acids.*
J. Chem. Soc., 119, 1152, 1408.

COHEN, L. J., AND GIES, W. J. [1908]. *A Study of "Protagon" Prepared by the Wilson-Cramer Method.*
Proc. Soc. Exp. Biol. and Med., 5, 97.

COHN, R. [1911]. *Beiträge zur Kenntniss des Lecithins.*
Zeitsch. öffentl. Chem., 17, 203.

COHN, R. [1913]. *Lecithinpräparate und die chemische Bestimmung des Lecithins.*
Zeitsch. öffentl. Chem., 19, 54.

COLLISON, R. C. [1912]. *A Brief Investigation on the Estimation of Lecithin.*
J. Biol. Chem., 11, 217.

CONTARDI, A. [1912]. *L'azione dell' acido fosforico concentrato sopra la glicerina*
Gaz. chim. ital., 42, II, 270

COOPER, E. A. [1914]. *The Relations of Vitamine to Lipoids.*
Biochem. J., 8, 347.

CORIAT, I. H. [1904]. *Production of Choline from Lecithin and Brain Tissue.*
Am. J. Physiol., 12, 353.

CORNER, G. W. [1917]. *Variation in the Amount of Phosphatides in the Corpus Luteum during Pregnancy.*
J. Biol. Chem., 29, 141.

CORRAN, J. W., AND LEWIS. W. C. McC. [1924]. *Lecithin and Cholesterol in relation to the Physical Nature of Cell Membranes.*
Biochem. J., 18, 1364.

COUERBE [1834]. *Du Cerveau considéré sous la point de vue chimique et physiologique.*
Ann. chim. phys., 56, 160.

COUSIN, H. [1903]. *Sur les acides gras de ia lécithine de l'oeuf.*
Compt. rend., 137, 68.

COUSIN, H. [1906]. *Sur les acides gras de la céphaline.*
Compt. rend. Soc. Biol., 2, 23.

COUSIN, H. [1906, 1]. *Sur les acides gras de la lécithine du cerveau*
J. Pharm. Chim. (VI), 23, 225.

COUSIN, H. [1907]. *Sur la nature des produits azotés obtenus dans la saponification de la céphaline.*
Compt. rend. Soc. Biol., 62, 238.

CRAMER, W. [1904]. *On Protagon, Cholin, and Neurin.*
J. Physiol., 31, 30.

CRAMER, W. [1910]. *A Comparison between the Properties of Protagon and the Properties of a Mixture of Phosphatides and Cerebrosides.*
Quart. J. Exp. Physiol., 3, 129.

CRAMER, W. [1911]. *Protagon, Cerebroside und verwandte Substanzen.*
Biochem. Handlexikon, herausg. von E. Abderhalden, 3, 250.

CRANNER, B. H. [1922]. *Zur Biochemie und Physiologie der Grenzschichten lebender Pflanzenzellen.*
Meld. fra Norges Landbr., p. 1.

CRUIKSHANK, J. [1913]. *On the Lecithin and other Lipoids Extracted from Formalin Fixed Tissues.*
J. Path. Bact., 17, 118.

CRUIKSHANK, J. [1913, 1]. *The Lecithin Content of Different Tissues.*
J. Path. Bact., 17, 134.

CRUIKSHANK, J. [1913, 2]. *"Lipoids" which Resemble Lecithin in forming Hæmolysins along with Cobra Venom.*
J. Path. Bact., 17, 619.

CRUIKSHANK, J. [1914]. *The Iodine Value of Lecithins.*
J. Path. Bact., 18, 428.

CRUTO, A. [1922]. *Constitution of Cerebrin.*
Rass. clin. terap. sci. affini, 21, 257; Physiol. Abs., 9, 107.

CZAPEK, F. [1910]. *Ueber eine Methode zur direkten Bestimmung der Oberflächenspannung der Plasmahaut von Pflanzenzellen.*
Ber. d. deutsch. botan. Ges., 38, 159, 480.

CZAPEK, F. [1913]. *Biochemie der Pflanzen.*
(Gustav Fischer, Jena, 1913.)

DANILEWSKY, B. [1895]. *De l'influence de la lécithine sur la croissance et la multiplication des organismes.*
Compt. rend., 121, 1167.

DARRAH, J. E., AND MACARTHUR, C. G. [1916]. *Nitrogenous Constituents of Brain Lecithin.*
J. Am. Chem. Soc., 38, 922.

DEILER, A. C., AND FRAPS, G. S. [1910]. *Pecan Oil.*
Am. Chem. J., 43, 90.

DELEZENNE, C., ET (MDLLE.) LEDEBT, S. [1911]. *Action du venin de cobra sur le cheval. Ses rapports avec l'hémolyse.*
Compt. rend., 152, 790.

DELEZENNE, C., ET (MDLLE.) LEDEBT, S. [1911, 1]. *Formation de substances hémolytiques et de substances toxiques aux dépens du vitellus de l'oeuf soumis a l'action du cobra.*
Compt. rend., 153, 81.

DELEZENNE, C., ET (MDLLE.) LEDEBT, S. [1912]. *Nouvelle contribution a l'étude des substances hémolytiques derivées du serum et du vitellus de l'oeuf soumis a l'action des venins.*
Compt. rend., 155, 1101.

DELEZENNE, C., ET FOURNEAU, E. [1914]. *Constitution du phosphatide hémolysant. (Lysocithine) provenant de l'action du venin de cobra sur le vitellus de l'oeuf de poulet*
Bull. Soc. Chim., iv, 15, 421.

DENIGÈS, G. [1909]. *Réactions colorées de la dioxyacétone.*
Compt. rend., 148, 172.

DESGREZ, A., ET ZAKY, A. [1902]. *Analyse du mode d'action des lécithines sur l'organisme animal.*
Compt. rend., 134, 1522.

DESGREZ, A., ET ZAKY, A. [1902, 1]. *De l'influence des lécithines sur le développement du squelette et du tissu nerveux.*
Compt. rend., 134, 1166.

DEZANI, S. [1909]. *Lecithin und Cholesterin welche im Sperma und in den Eierstocken des Thunfisches enthalten sind.*
Chem. Centr., II, 637.

DIACONOW, C. [1867]. *Ueber die phosphorhaltigen Körper der Hühner-und Storeier.*
Hoppe-Seyler Med. Chem. Untersuch., 2, 221.

DIACONOW, C. [1867, 1]. *Entstehungsart der Phosphate in den Knochen und den Muskeln.*
Centr. Med. Wissensch., No. 43, 673.

DIACONOW, C. [1868]. *Ueber die chemische Constitution des Lecithin.*
Centr. Med. Wissensch., No. 1, 2.

DIACONOW, C. [1868, 1]. *Das Lecithin im Gehirn.*
Centr. Med. Wissensch., No. 7, 97.

DIACONOW, C. [1868, 2]. *Ueber die chemische Constitution des Lecithin.*
Centr. Med. Wissensch., No. 28, 434.

DIACONOW, C. [1868, 3]. *Ueber das Lecithin.*
Hoppe-Seyler Med. Chem. Untersuch., 3, 405.

DINKIN, L., UND KLEIN, W. [1914]. *Beiträge zur Kenntniss des menschlichen Serums und zur Methodik der Lipoidbestimmung.*
Zeitsch. physiol. Chem., 92, 302.

DRECHSEL, E. [1886]. *Ueber einen neuen schwefel- und phosphorhaltigen Bestandtheil der Leber.*
J. prakt. Chem., 33, 425.

DRECHSEL, E. [1896]. *Beiträge zur Chemie einiger Seethiere.*
Zeitsch. Biol., 33, 85.

DUDGEON, L. S. [1906]. *Changes in Tissue in Acute Diphtheritic Toxæmia.*
Brain, p. 227.

DUNHAM, E. K. [1905]. *Further Observations upon the Phosphorized Fats in Extracts of the Kidney.*
Proc. Soc. Exp. Biol. Med., 2, 63.

DUNHAM, E. K. [1908]. *The Isolation of Carnaubic Acid from Beef Kidney.*
J. Biol. Chem., 4, 297.

DUNHAM, E. K., AND JACOBSON, C. A. [1910]. *Über Carnaubon: Ein glycerinfreies Phosphatid, lecithinähnlich konstituiert mit Galaktose als Kern.*
Zeitsch. physiol. Chem., 64, 303.

EAVES, E. C. [1910]. *The Transformations in the Fats in the Hen's Egg during Development.*
J. Physiol., 40, 451.

ECKSTEIN, H. C. [1922]. *Fat Transport in the Body.*
Proc. Soc. Exp. Biol. Med., 20, 74.

ECKSTEIN, H. C. [1925]. *Synthesis of Lecithin in the Animal Organism.* J. Biol. Chem., **62**, 743.

EDMED, F. G. [1898]. *Constitution of Oleic Acid and its Derivatives.* J. Chem. Soc., **73**, 627.

EHRENFELD, R. [1908]. *Über Molybdän-verbindungen des Lecithins.* Zeitsch. physiol. Chem., **56**, 89.

EICHOLTZ, F. [1924]. *Ueber die Resorption von Lecithin.* Biochem. Zeitsch., **144**, 66.

ENGELAND, R. [1909]. *Über Hydrolyse von Casein und den Nachweis der dabei entstandenen monaminosäuren.* Ber., **42**, 2962.

EPPLER, J. [1913]. *Untersuchungen über Phosphatide, inbesondere über die im Eigelb vorhandenen.* Zeitsch. physiol. Chem., **87**, 233.

ERLANDSEN, A. [1907]. *Untersuchungen über die lecithinartigen Substanzen des Myocardiums und der quergestreiften Muskeln.* Zeitsch. physiol. Chem., **51**, 71.

EULER, H., UND NORDENSON, E. [1908]. *Zur Kenntniss des Möhrencarotens und seiner Begleitsubstanzen.* Zeitsch. physiol. Chem., **56**, 223.

FALK, F. [1908]. *Über die chemische Zusammensetzung der peripheren Nerven.* Biochem. Zeitsch., **13**, 153.

FAURE-FREMIET, I. E. [1915]. *Composition et Morphologie des Lipõides ovulaires.* J. Physiol. path. gen., **xvi**, 808.

FEINSCHMIDT, J. [1912]. *Die Säureflockung von Lecithinen und Lecithin Eiweissgemischen.* Biochem. Zeitsch., **38**, 244.

FENGER, F. [1916]. *Phosphatides in the Ductless Glands.* J. Biol. Chem., **27**, 303.

FINGERLING, G. [1912]. *Die Bildung von organischen Phosphor-verbindungen aus anorganischen Phosphaten.* Biochem. Zeitsch., **38**, 448.

FINGERLING, G. [1912, 1]. *Einfluss organischer und anorganischer Phosphor-verbindungen auf die Milchsekretion.* Biochem. Zeitsch., **39**, 239.

FISCHER, H. [1865]. *Zur Lehre von der Pyaemia—Zur chemische Natur des Eiters.* Centr. med. Wissensch., No. 15, 225.

FISCHER, H. [1868]. *Zur Lehre von der Pyaemia—Zur chemische Natur des Eiters.* Centr. med. Wissensch., No. 42, 659.

FISCHER, M. H., UND HOOKER, M. O. [1916]. *Ueber die Analogie des Verhaltens von Emulsionen und des Verhaltens von Fett im Protoplasma.* Kolloid-Zeitsch., **18**, 242.

FOSTER, M. L. [1915]. *Studies on a Method for the Quantitative Estimation of Certain Groups in Phospholipins.* J. Biol. Chem., **20**, 403.

FOURCROY, A. F. [1793]. *Examen chimique du cerveau de plusieurs animaux.* Ann. de Chim., **16**, 282.

FOURNEAU, E. [1920]. *Les Phosphatides.* Bull. soc. Chim. Biol., **2**, 67.

FOURNEAU ET PIETTRE, M. M. [1912]. *Analyse immédiate des lipoides complexes par alcoolyse.* Bull. soc. Chim. (IV), **11**, 805.

FRANCHINI, G. [1907]. *Über den Ansatz von Lecithin und sein Verhalten im Organismus.* Biochem. Zeitsch., **6**, 210.

FRANK, A. [1913]. *Über das Vorkommen von Kephalin und Trimyristin in der Leber.* Biochem. Zeitsch., **50**, 273.

FRÄNKEL, S. [1909]. *Gehirn-Chemie.* Ergeb. d. Physiol., **8**, 212.

FRÄNKEL, S. [1909, 1] *Über ein neues Verfahren der Fraktionierten Extraktion der Gehirnlipoide.*
Biochem. Zeitsch., **19**, 254.

FRÄNKEL, S. [1911]. *Darstellung von Lipoiden aus Gehirn und anderen Geweben.*
Handbuch biochem. Arbeitsmethoden (Abderhalden), **5**, 613.

FRÄNKEL, S., UND BOLAFFIO, C. [1908]. *Über das Neottin ein triaminomonophosphatid.*
Biochem. Zeitsch., **9**, 44.

FRÄNKEL, S., UND DIMITZ, L. [1909]. *Über die Spaltungsprodukte des Kephalins.*
Biochem. Zeitsch., **21**, 337.

FRÄNKEL, S., UND DIMITZ, L. [1910]. *Die chemische Zusammensetzung des Rückenmarks.*
Biochem. Zeitsch., **28**, 295.

FRÄNKEL, S., UND ELFER, A. [1910]. *Über ein Verfahren der Serumtrocknung.*
Biochem. Zeitsch., **28**, 330.

FRÄNKEL, S., UND ELFER, A. [1912]. *Über das Trocknen von Geweben und Blut für die Darstellung von Lipoiden.*
Biochem. Zeitsch., **40**, 138.

FRÄNKEL, S., UND ELIAS, H. [1910] *Über Leukopoliin.*
Biochem. Zeitsch., **28**, 320.

FRÄNKEL, S., UND GILBERT, O [1921]. *Ueber die Darstellung von Phosphorsulphatiden aus Gehirn.*
Biochem. Zeitsch., **124**, 206.

FRÄNKEL, S., UND KAFKA, F. [1920]. *Die Lipoide.* XVII. *Ueber den Dilignoceryl-N-diglucosaminmonophosphor säureester, ein neues Diaminomonophosphatid aus Gehirn.*
Biochem. Zeitsch., **101**, 159.

FRÄNKEL, S., UND KARPFEN, O. [1925]. *Hypohirnsäure.*
Biochem. Zeitsch., **157**, 414.

FRÄNKEL, S., UND KÄSZ, A. [1921]. *Ueber ein Lecithin aus Menschenhirn.*
Biochem. Zeitsch., **124**, 216.

FRÄNKEL, S., UND LINNERT, K. [1910]. *Über das Sahidin aus Menschenhirn.*
Biochem. Zeitsch., **24**, 268.

FRÄNKEL, S., UND LINNERT, K. [1910, 1]. *Über den Nachweis von Galaktose in Lipoiden.*
Biochem. Zeitsch., **26**, 41.

FRÄNKEL, S., UND LINNERT, K. [1910, 2]. *Vergleichend-chemische Gehirn untersuchungen.*
Biochem. Zeitsch., **26**, 44.

FRÄNKEL, S., LINNERT, K., UND PARI, G. A. [1909]. *Über die Phosphatide des Rinderpankreas.*
Biochem. Zeitsch., **18**, 37.

FRÄNKEL, S., UND NEUBAUER, E. [1909]. *Über Kephalin.*
Biochem. Zeitsch., **21**, 320.

FRÄNKEL, S., UND NOGUEIRA, A. [1909]. *Über die ungesättigten Phosphatide der Niere.*
Biochem. Zeitsch., **16**, 366.

FRÄNKEL, S., UND OFFER, T. R. [1910]. *Über die Phosphatide des Pferdepankreas.*
Biochem. Zeitsch., **26**, 53.

FRÄNKEL, S., UND PARI, G. A. [1909]. *Über die Phosphatide des Rinderpankreas.*
Biochem. Zeitsch., **17**, 68.

FRANKFURT, S. [1894]. *Über die Zusammensetzung der Samen und der etiolierten Keimpflanzen von Cannabis sativa und Helianthus annuus.*
Landw. Versuchstat., **43**, 143.

FRÉMY, E. [1841]. *Recherches sur le cerveau.*
Ann. chim. phys., 3me Ser., **2**, 463.

FRÉMY, E. [1841, 1]. *Recherches sur le cerveau.*
J. de pharm., **27**, 453.

FRÉMY, E. [1841, 2]. *Untersuchungen über das Gehirn.*
Ann. Chem. Pharm., **39**, 69.

FRÉMY, E., ET VALENCIENNE [1857]. *Recherches sur la Composition des oeufs et des muscles dans la série des animaux.*
Ann. Chim. et Phys., Series III, **50**, 127.

FREUNDLER, M. P. [1912]. *Sur le dosage du phosphore dans la lécithine.* Bull. soc. Chim. (4), **2**, 1041.

FUNK, C. [1911]. *On the Chemical Nature of the Substance which cures Polyneuritis in Birds induced by a Diet of Polished Rice.* J. Physiol., **43**, 395.

FUNK, C. [1912]. *The Effect of a Diet of Polished Rice on the Nitrogen and Phosphorus of the Brain.* J. Physiol., **44**, 50.

GALEOTTI, G., UND GIAMPALMO, G. [1908]. *Ricerche sulle lecitalbumine.* Arch. Fisiol., **5**, 503.

GAMGEE, A., UND BLANKENHORN, E. [1879]. *Ueber Protagon.* Zeitsch. physiol. Chem., **3**, 260.

GAMGEE, A. [1880]. *A Text-book of the Physiological Chemistry of the Animal Body.* (London, 1880), p. 441.

GAMGEE, A. [1880, 1]. *A Note on Protagon.* Proc. Roy. Soc., **30**, 111.

GEOGHEGAN, E. G. [1879]. *Ueber die Constitution des Cerebrins.* Zeitsch. physiol. Chem., **3**, 332.

GERARD, E., ET VERHAEGHE, M. [1911]. *Contribution a l'étude des lipoides des organes animaux.* J. Pharm. Chim. (VII), **3**, 385.

GIES, W. J. [1907]. *Further Observations on Protagon.* J. Biol. Chem., **3**, 339.

GILSON, E. [1888]. *Beiträge zur Kenntniss des Lecithins.* Zeitsch. Physiol. Chem., **12**, 585.

GLIKIN, W. [1907]. *Uber den Lecithingehalt des Knochenmarks bei Tieren und beim Menschen.* Biochem. Zeitsch., **4**, 235.

GLIKIN, W. [1907, 1]. *Zur biologischen Bedeutung des Lecithins.* Biochem. Zeitsch., **7**, 286.

GLIKIN, W. [1908]. *Über den Eisengehalt der Fette, Lipoide und Wachsarten.* Ber., **41**, 910.

GLIKIN, W. [1909]. *Zur biologischen Bedeutung des Lecithins. Über den Lecithin-und Eisengehalt in der Kuh-und Frauenmilch.* Biochem. Zeitsch., **21**, 348.

GOBLEY, M. [1846]. *Recherches chimiques sur le jaune d'oeuf.* J. Pharm. Chim., 3me Ser., **9**, 1, 81, 161.

GOBLEY, M. [1847]. *Recherches chimiques sur le jaune de l'oeuf. Examen comparatif du jaune d'oeuf et de la matière cérebrale.* J. Pharm. Chim., **11**, 409; **12**, 1.

GOBLEY, M. [1850]. *Recherches chimiques sur les oeufs de carpe.* J. Pharm. Chim., 3me Ser., **17**, 401.

GOLDFARB, A. J. [1910]. *Does Lecithin Influence Growth?* Arch. Entwickelungsmech. Org., **29**, 255

GORTER, E., AND GREUDEL, F. [1925]. *On Bimolecular Layers of Lipoids on the Chromocytes of Blood.* J. Exp. Med., **41**, 439.

GORUP-BESANEZ [1878]. Lehrbuch d. physiol. Chemie, 4 Aufl. (Braunschweig).

GRAFE. V. [1925]. *Zur Physiologie und Chemie der Pflanzenphosphatide.* Biochem. Zeitsch., **159**, 444.

GRAFE, V., UND HORVAT, V. [1925]. *Die Wasserlöslichen Phosphatide aus der Wurzel der Zuckerrübe.* Biochem. Zeitsch., **159**, 449.

GREEN, J. REYNOLDS, AND JACKSON, H. [1905]. *Further Observations on the Germination of the Seeds of the Castor-oil Plant (Ricinus Communis).* Proc. Roy. Soc., **77**, B, 69.

GREENWALD, I. [1915]. *The Estimation of Lipoid and Acid-soluble Phosphorus in Small Amounts of Serum.* J. Biol. Chem., **21**, 29.

GREGERSEN, J. P. [1911]. *Untersuchungen über den Phosphorstoffwechsel.* Zeitsch. physiol. Chem., 71, 49.

GREY, E. C. [1913]. *The Fatty Acids of the Human Brain.* Biochem. J., 7, 148.

GRIGAUT, A., AND YOVANOVITCH, R. [1925]. *Lipogenèse et lipoidogenèse dans l' Organisme animal.* Compt. rend. Soc. Biol., 92, 17.

GRIMBERT, L., ET BAILLY, O. [1915]. *Sur un procédé de diagnose des monoéthers glycérophosphoriques et sur la constitution du glycérophosphate de sodium cristallisé.* Compt. rend., 160, 207.

GRIMBERT, L., ET BAILLY, O. [1915, 1]. *Sur un procédé de diagnose des monoéthers glycérophosphoriques et sur la constitution du glycérophosphate de sodium cristallisé.* J. Pharm. Chim. (VII), 11, 153.

GRIMBERT, L., ET LAUDAT, M. [1912]. *Sur le dosage des lipoides dans le sérum sanguin.* Compt. rend., 155, 974.

GROSSER, P., UND HUSLER, J. [1912]. *Über das Vorkommen einer glycerophosphatase in tierischen Organen.* Biochem. Zeitsch., 39, 1.

GRÜN, A. [1905]. *Beitrag zur Synthese der Fette.* Ber., 38, 2284.

GRÜN, A., UND KADE, F. [1912]. *Zur Synthese der Lecithine.* Ber., 45, 3367.

GRÜN, A., UND KADE, F. [1912, 1]. *Zur Kenntniss der Diglycerid phosphorsäuren.* Ber., 45, 3358.

GULEWITSCH, WL. [1898]. *Ueber Cholin und einiger Verbindungen desselben.* Zeitsch. physiol. Chem., 24, 513.

HAMMARSTEN, O. [1902]. *Untersuchungen über die Gallen einiger Polarthiere.* Zeitsch. physiol. Chem., 36, 525.

HAMMARSTEN, O [1904]. *A Text-Book of Physiological Chemistry.* (Translated Mendel), p. 409.

HANDOVSKY, H., UND WAGNER, R. [1911]. *Über einige physikalisch-chemische Eigenschaften von Lecithin-emulsionen und Lecithineiweissmischungen.* Biochem. Zeitsch., 31, 32.

HARTLEY, P. [1909]. *On the Nature of the Fat contained in the Liver, Kidney and Heart.* J. Physiol., 37, 353.

HATAI, S. [1904]. *The Effect of Lecithin on the Growth of the White Rat.* Am. J. Physiol., 10, 57.

HECKEL, E., UND SCHLAGDENHAUFFEN, FR. [1886]. *Sur la présence de la lécithine dans les végétaux.* J. Pharm. Chim., 14, 213.

HEFFTER, A. [1891]. *Das Lecithin in der Leber und sein Verhalten bei der Phosphorvergiftung.* Arch. exp. Path. Pharm., 28, 97.

HEFFTER, A. [1891, 1]. *Lecithin in der Leber.* Inaug. Diss., Leipzig, 1890 ; Chem. Centr., 1891, 1, 459.

HELL, C., UND HERMANNS, O. [1880]. *Ueber Lignocerinsäure.* Ber., 13, 1713.

HENRIQUES, V. [1897]. *Ueber die reducirenden Stoffe des Blutes.* Zeitsch. physiol. Chem., 23, 244.

HENRIQUES, V., UND HANSEN, C. [1903]. *Ueber den Uebergang des Nahrungsfettes in das Hühnerei und über die Fettsaüre des Lecithins.* Skand. Arch. Physiol., 14, 390.

HERMANN, L. [1866]. *Protagon im Blute.* Zeitsch. analyt. Chem., 5, 262.

HERRMANN, E., UND NEUMANN, J. [1912]. *Ueber den Lipoidgehalt des Blutes normalen und schwangerer Frauen sowie neugeborener Kinder.* Biochem. Zeitsch., 43, 47.

HESS, A. F., AND HELMAN, F. D. [1925]. *The phosphatide and Total Phosphorus Content of Woman's and Cow's Milk.* J. Biol. Chem., 64, 781.

HESSE, O. [1878]. *Ueber Phytosterin und Cholesterin.* Ann. Chem., **192**, 175.

HEUBNER, W. [1908]. *Beobachtungen über die Zersetzlichkeit des Lecithins.* Arch. exp. Path., 59, 420.

HIESTAND, O. [1906]. *Beiträge zur Kenntniss der Pflanzlichen Phosphatide.* (Inaug. Diss., Zurich.)

HOLDE, D. [1905]. *Ueber die natürlich vorkommende Heptadecylsaüre.* Ber., 38, 1247.

HOPKINS, F. G. [1912]. *Feeding Experiments illustrating the Importance of Accessory Factors in Normal Dietaries.* J. Physiol., 44, 425.

HOPKINS, F. G. [1921]. *On an autoxidisable Constituent of the Cell.* Biochem. J., 15, 286.

HOPKINS, F. G. [1925]. *Glutathione: Its Influence in the Oxidation of Fats and Proteins.* Biochem. J., 19, 787.

HOPKINS, F. G., AND DIXON, M. [1922]. *A thermostable Oxidation-reduction System.* J. Biol. Chem., 54, 527.

HOPPE-SEYLER, F. [1866]. *Beiträge zur Kenntniss der constitution des Blutes. Ueber das Vorkommen von Cholesterin und Protagon und ihre Betheiligung bei der Bildung des Stroma der rothen Blutkörperchen.* Hoppe-Seyler Med. Chem. Unters., 1, 140.

HOPPE-SEYLER, F. [1886, 1]. *Ueber einige Bestandtheile der Maiskörner.* Hoppe-Seyler Med. Chem. Unters., 1, 162.

HOPPE-SEYLER, F. [1867]. *Ueber das Vitellin, Ichthin und ihre Beziehung zu den Eiweissstoffen.* Hoppe-Seyler Med. Chem. Unters., 2, 215

HOPPE-SEYLER, F. [1869]. *Ueber die Zusammensetzung der Blutkörperchen des Igel und Coluber natrix.* Hoppe-Seyler Med. Chem. Unters., 3, 392.

HOPPE-SEYLER, F. [1871]. *Ueber die chemische Zusammensetzung des Eiters.* Hoppe-Seyler Med. Chem. Unters., 4, 486.

HOPPE-SEYLER, F. [1879]. *Ueber Lecithin und Nuclein in der Bierhefe.* Zeitsch. f. physiol. Chem., 2, 427.

HOPPE-SEYLER, F. [1879]. *Ueber Lecithin in der Hefe.* Zeitsch. f. physiol. Chem., 3, 374.

HOWELL, W. H. [1911]. *The Rôle of Antithrombin and Thromboplastin (Thromboplastic Substance) in the Coagulation of Blood.* Amer. J. Physiol., 29, 187.

HOWELL, W. H. [1912]. *The Nature and Action of the Thromboplastic (Zymoplastic) Substance of the Tissues.* Amer. J. Physiol., 31, 1.

HUNDESHAGEN, F. [1883]. *Zur Synthese des Lecithins.* J. pr. Chem. (2), 28, 219.

ISCOVESCO, H. [1912]. *Propriétés physiologiques de certains lipoides. Les Lipoides homo- et hétero-stimulants des Organes.* Compt. rend. Soc. Biol., 73, 16.

IWANOFF, L. [1902]. *Über die Umwandlung des Phosphors beim Keimen der Wicke.* Chem. Centr., ii, 1001.

JACOBSEN, A. [1892]. *Ueber die reducirenden Substanzen des Blutes.* Centr. Physiol., 6, 368.

JACOBSEN, A. [1895]. *Ueber die in Aether löslichen reducirenden Substanzen des Blutes und der Leber.* Skand. Arch. Physiol., 6, 262.

JACOBSON, H. [1889]. *Ueber einige Pflanzenfette.* Zeitsch. physiol. Chem., 13, 32.

JOHNSON, M. [1913]. *The Control of Pigment Formation in Amphibian Larvæ.* Univ. California Publ., Zoology, 11, 53.

JÜDELL, G. [1869]. *Zur Blutanalyse.* Hoppe-Seyler Med. Chem. Unters., 3, 386.

KAWAMURA, R. [1911]. *Die Cholesterinesterverfettung.* (Jena, 1911.)

KENNAWAY, E. L., AND LEATHES, J. B. [1909]. *Fat in the Liver in Health and Disease.* Proc. Roy. Soc. Med., Feb.

KEPINOW, L. [1911]. *Über den Einfluss der Blutkorperchen Lipoide auf die Blutbildung.* Biochem. Zeitsch., 30, 160.

KING, H. D. [1907]. *Food as a Factor in the Determination of Sex in Amphibians.* Biol. Bull., 13, 40.

KING, H., AND PYMAN, F. L. [1914]. *The Constitution of the Glycerophosphates; the Synthesis of α- and β-glycerophosphates.* J. Chem. Soc., 105, 1328.

KITAGAWA, F., UND THIERFELDER, H. [1906]. *Über das Cerebron.* Zeitsch. physiol. Chem., 49, 286.

KLENK, E. [1925]. *Ueber ein neues Cerebrosid des Gehirns.* Zeitsch. f. physiol. Chem., 145, 244.

KLENK, E. [1926]. *Ueber die Nervonsaure.* Zeitsch. physiol. Chem., 157, 282.

KLENK, E. [1926, 1]. *Ueber eine Säure,* $C_{24}H_{46}O_3$ *aus Cerebrosiden des Gehirns.* Zeitsch. physiol. Chem., 157, 291.

KNOOP, F. [1905]. *Der Abbau aromatischer Fettsaüren im Tierkorper.* Beitr. chem. Physiol. Path., 6, 150.

KNOP, W. [1860]. *Ueber ein phosphorhaltiges Oel der Erbsen.* Landw. Versuchstat., 1, 26.

KOCH, W. [1902]. *Zur Kenntniss des Lecithins, Kephalins und Cerebrins aus Nervensubstanz.* Zeitsch. physiol. Chem., 36, 134.

KOCH, W. [1903]. *Die Lecithane und ihre Bedeutung für die lebende Zelle.* Zeitsch. physiol. Chem., 37, 181.

KOCH, W. [1904]. *Methods for the Quantitative Chemical Analysis of the Brain and Cord.* Am. J. Physiol., 11, 303.

KOCH, W. [1906]. *Über den Lecithingehalt der Milch.* Zeitsch. physiol. Chem., 47, 327.

KOCH, W. [1907]. *The Relation of Electrolytes to Lecithin and Kephalin.* J. Biol. Chem., 3, 53.

KOCH, W. [1907, 1]. *Zur Kenntniss der Schwefelverbindungen des Nervensystems.* Zeitsch. physiol. Chem., 53, 496.

KOCH, W. [1909]. *Die Bedeutung der Phosphatide (Lecithane) für die lebende Zelle.* Zeitsch. physiol. Chem., 63, 432.

KOCH, W., AND WOODS, H. S. [1905]. *The Quantitative Estimation of the Lecithans.* J. Biol. Chem., 1, 203.

KÖHLER, H. [1867]. *Ueber die chemische Zusammensetzung und Bedeutung des sogenannten Myelins.* Arch. path. Anat. u. Physiol., 41, 265.

KOSSEL, A., UND FREYTAG, FR. [1893]. *Ueber einige Bestandtheile des Nervenmarks end ihre Verbreitung in den Geweben des Thierkörpers.* Zeitsch. physiol. Chem., 17, 431.

KRAFFT, F. [1882]. *Ueber neunzehn höhere Normalparaffine* C_nH_{2n+2} *und ein einfaches Volumgesetz fur den tropfbar flüssigen Zustand.* Ber., 15, 1711.

KREILING, P. [1888]. *Ueber das Vorkommen von Lignocerinsäure* $C_{24}H_{48}O_2$ *neben Arachinsäure* $C_{20}H_{40}O_2$ *im Erdnussöl.* Ber., 21, 880.

KÜTTNER, S. [1907]. *Über den Einfluss des Lecithins auf die Wirkung der Verdaungsfermente.* Zeitsch. physiol. Chem., 50, 472.

KYES, P. [1903]. *Über die Isolierung von Schlangengift Lecithiden.* Berl. Klin. Wochenschr., 956 and 982.

KYES, P. [1907]. *Ueber die Lecithide des Schlangengiftes.* Biochem. Zeitsch., 4, 99.

KYES, P. [1908]. *Bemerkungen ueber die Lecithidbildung.* Biochem. Zeitsch., 8, 42.

LANGHELD, K. [1911]. *Über Ester und Amide der Phosphorsäuren.* II. *Uber Versuche zur Darstellung den Lecithinen verwandter Körper.* Ber., 44, 2076.

LAPIDUS, H. [1910]. *Diastase und Handelslecithin.* Biochem. Zeitsch., 30, 39.

LAPWORTH, A. [1913]. *Oxidation of Sphingosine and the Isolation and Purification of Cerebrone.* J. Chem. Soc., 103, 1029.

LEATHES, J. B. [1910]. *The Fats.* First edition (Longmans & Co., London).

LEATHES, J. B. [1923]. *The Behaviour of Lecithine, Hydrolecithine and Cholesterol in Monomolecular Films.* J. Physiol., 58, Proc. VI.

LEATHES, J. B. [1925]. *Croonian Lectures.* Lancet, pp. 803, 853, 957, 1019.

LEATHES, J. B., AND MEYER-WEDELL, L. [1909]. *On the Desaturation of Fatty Acids in the Liver.* J. Physiol., 38, Proc. VI.

LEATHES, J. B., AND RAPER, H. S. [1925]. *The Fats.* (Longmans.)

LEHMANN, O. [1904]. *Flüssige Kristalle.* (Leipzig.)

LEHMANN, O. [1914]. *Flüssige Kristalle und Biologie.* Biochem. Zeitsch., 63, 74.

LEMELAND, P. [1921]. *Recherches Chimiques et Biologiques sur le Dosage des Lipoides. Etude critique de la methode de Kumagawa Suto.* Bull. Soc. Chim. Biol., 3, 134.

LEMELAND, P. [1922]. *Recherches Chimiques et Physiologiques sur les Matieres grasses et les Lipoides du Sang.* Bull. Soc. Chim. Biol., 4, 300.

LESEM, W. W., AND GIES, W. J. [1903]. *Notes on the "Protagon" of the Brain.* Am. J. Physiol., 8, 183.

LETSCHE, E. [1907]. *Beiträge zur Kenntniss der organischen Bestandteile des Serums.* Zeitsch. physiol. Chem., 53, 31.

LEVENE, P. A. [1907]. *Personal Communication to Koch.* Zeitsch. physiol. Chem., 53, 499.

LEVENE, P. A. [1912]. *The Sulphatide of the Brain.* J. Biol. Chem., 13, 463.

LEVENE, P. A. [1913]. *Sphingomyelin. On the Presence of Lignoceric Acid among the Products of Hydrolysis of Sphingomyelin.* J. Biol. Chem., 15, 153.

LEVENE, P. A. [1913, 1]. *On the Cerebrosides of the Brain Tissue.* J. Biol. Chem., 15, 359.

LEVENE, P. A. [1914]. *On Sphingomyelin.* J. Biol. Chem., 18, 453.

LEVENE, P. A. [1916]. *Sphingomyelin.* J. Biol. Chem., 24, 69.

LEVENE, P. A. [1921]. *Structure and Significance of the Phosphatides.* Physiol. Reviews, 1, 327.

LEVENE, P. A., AND HALLER, H. L. [1925]. *On Sphingosine. V. The synthesis of 1-amino 2-hydroxy n-heptacdecane.* J. Biol. Chem., 63, 669.

LEVENE, P. A., AND INGVALDSEN, T. [1920]. *The Estimation of Aminoethanol and of Choline appearing on Hydrolysis of Phosphatides.* J. Biol. Chem., 43, 355.

LEVENE, P. A., AND INGVALDSEN, T. [1920, 1]. *Unsaturated Lipoids of the Liver.* J. Biol. Chem., 43, 359.

LEVENE, P. A., AND JACOBS, W. A. [1911]. *On Sphingosine.*
J. Biol. Chem., 11 ; Proc. Am. Soc. Biol. Chem., xxix.

LEVENE, P. A., AND JACOBS, W A. [1912]. *On Sphingosine.*
J. Biol. Chem., 11, 547.

LEVENE, P. A., AND JACOBS, W. A. [1912, 1]. *On Cerebronic Acid.*
J. Biol. Chem., 12, 381.

LEVENE, P. A., AND JACOBS, W. A. [1912, 2]. *On the Cerebrosides of the Brain Tissue.*
J. Biol. Chem., 12, 389.

LEVENE, P. A., AND KOMATSU, S. [1919]. *Lipoids of the Heart Muscle.*
J. Biol. Chem., 39, 83.

LEVENE, P. A., AND KOMATSU, S. [1919, 1]. *Cephalin. VI. The Bearing of Cuorin on the Structure of Cephalin.*
J. Biol. Chem., 39, 91.

LEVENE, P. A., AND ROLF, I. P. [1919]. *Cephalin.* VII. *The Glycerophosphoric Acid of Cephalin.*
J. Biol. Chem., 40, 1.

LEVENE, P. A., AND ROLF, I. P. [1921]. *Lecithin.* III. *Fatty Acids of Lecithin of the Egg-Yolk.*
J. Biol. Chem., 46, 193.

LEVENE, P. A., AND ROLF, I. P. [1921, 1]. *Lecithin.* IV. *Lecithin of the Brain.*
J. Biol. Chem., 46, 353.

LEVENE, P. A., AND ROLF, I. P. [1922]. *The Unsaturated Fatty Acids of Egg.*
J. Biol. Chem., 51, 507.

LEVENE, P. A., AND ROLF, I. P. [1922, 1]. *Unsaturated Fatty Acids of Brain Cephalins.*
J. Biol. Chem., 54, 91.

LEVENE, P. A., AND ROLF, I. P. [1922, 2]. *Unsaturated Fatty Acids of Brain Lecithins.*
J. Biol. Chem., 54, 99.

LEVENE, P. A., AND ROLF, I. P. [1923]. *Lysolecithins and Lysocephalins.*
J. Biol. Chem., 55, 743.

LEVENE, P. A., AND ROLF, I. P. [1924]. *Synthetic Lecithins.*
J. Biol. Chem., 60, 677.

LEVENE, P. A., ROLF, I. P., AND SIMMS, H. S. [1924]. *Lysolecithins and Lysocephalins.* II. *Isolation and Properties of Lysolecithins and Lysocephalins.*
J. Biol. Chem., 58, 859.

LEVENE, P. A., AND ROLF, I. P. [1925]. *Lecithin and Cephalin of Soy Bean.*
J. Biol. Chem., 62, 759.

LEVENE, P. A., AND ROLF, I. P. [1925, 1]. *Bromolecithins.* I. *Fractionation of Brominated Soy Bean Lecithins.*
J. Biol. Chem., 65, 545.

LEVENE, P. A., AND ROLF, I. P. [1926]. II. *Bromolecithins of the Liver and Egg-yolk.*
J. Biol. Chem., 67, 659.

LEVENE, P. A., AND SIMMS, H. S. [1921]. *The Liver Lecithin.*
J. Biol. Chem., 48, 185.

LEVENE, P. A., AND SIMMS, H. S. [1922]. *The Unsaturated Fatty Acids of Liver Lecithin.*
J. Biol. Chem., 51, 285.

LEVENE, P. A., AND TAYLOR, F. A. [1922]. *Lignoceric Acid. Synthesis of Hydroxypentacosanic Acid.*
J. Biol. Chem., 52, 227.

LEVENE, P. A., TAYLOR, F. A., AND HALLER, H. L. [1924]. *Lignoceric Acid.*
J. Biol. Chem., 61, 157.

LEVENE, P. A., AND WEST, C. J. [1913]. *On Cerebronic Acid.*
J. Biol. Chem., 14, 257.

LEVENE, P. A., AND WEST, C. J. [1913, 1]. *On Cerebronic Acid ; its Bearing on the Constitution of Lignoceric Acid.*
J. Biol. Chem., 15, 193.

LEVENE, P. A., AND WEST, C. J. [1913, 2]. *The Saturated Fatty Acid of Kephalin.*
J. Biol. Chem., 16, 419.

LEVENE, P. A., AND WEST, C. J. [1914]. *On Sphingosine. The Oxidation of Sphingosine and Dihydrosphingosine.*
J. Biol. Chem., 16, 549.

LEVENE, P. A., AND WEST, C. J. [1914, 1]. *On Cerebronic Acid ; on the Constitution of Lignoceric Acid.*
J. Biol. Chem., **18**, 477.

LEVENE, P. A., AND WEST, C. J. [1914, 2]. *On Sphingosine. The Oxidation of Sphingosine and Dihydrosphingosine.*
J. Biol. Chem., **18**, 481.

LEVENE, P. A., AND WEST, C. J. [1916]. *Brain Cephalin.*
J. Biol. Chem., **24**, 41.

LEVENE, P. A., AND WEST, C. J. [1916, 1]. *Sphingosine ; Some Derivatives of Sphingosine and Dihydrosphingosine.*
J. Biol. Chem., **24**, 63.

LEVENE, P. A., AND WEST, C. J. [1916, 2]. *Cephalin of the Egg-Yolk, Kidney and Liver.*
J. Biol. Chem., **24**, 111.

LEVENE, P. A., AND WEST, C. J. [1916, 3]. *Cephalin.* IV. *Phenyl and Naphthylureidocephalin.*
J. Biol. Chem., **25**, 517.

LEVENE, P. A., AND WEST, C. J. [1916, 4]. *Cerebronic Acid. Relation of Cerebronic and Lignoceric Acids.*
J. Biol. Chem., **26**, 115.

LEVENE, P. A., AND WEST, C. J. [1918]. *Hydrolecithin and Bearing on Constitution of Cephalin.*
J. Biol. Chem., **33**, 111.

LEVENE, P. A., AND WEST, C. J. [1918, 1]. *Lecithin.* II. *Preparation of Pure Lecithin ; Composition and Stability of Lecithin Cadmium Chloride.*
J. Biol. Chem., **34**, 175.

LEVENE, P. A., AND WEST, C. J. [1918, 2]. *Cephalin.* V. *Hydrocephalin of Egg-Yolk.*
J. Biol. Chem., **35**, 285.

LEVENE, P. A., WEST, C. J., ALLEN, C. H., AND SCHEER, J. VAN DER [1915]. *Synthesis of Normal Tridecylic and Tetracosanic Acids.*
J. Biol. Chem., **23**, 71.

LEWKOWITSCH, J. [1913]. *Oils, Fats and Waxes.* Vol. I. (5th edition).
(Macmillan & Co., London.)

LIEBERMANN, L. [1893]. *Neuere Untersuchungen über das Lecithalbumin.*
Archiv. f. Ges. Physiol., **54**, 573.

LIEBREICH, O. [1865]. *Ueber die chemische Beschaffenheit der Gehirnsubstanz.*
Ann. Chem. Pharm., **134**, 29.

LILIENFELD, L. [1893]. *Zur Chemie der Leucocyten.*
Zeitsch. physiol. Chem., **18**, 473.

LIPPMANN, E. O. VON [1887]. *Ueber einige organische Bestandtheile des Rubensaftes.*
Ber., **20**, 3201.

LOEB, J., AND BEUTNER, B. [1913]. *Die Bedeutung der Lipoide für die Entstehung der bioelektrischen Potentialdifferenzen bei gewissen pflanzlichen Organen.*
Biochem. Zeitsch., **51**, 288.

LOEB, J., AND BEUTNER, R. [1914]. *Ueber die Bedeutung der Lipoide für die Entstehung von Potentialunterschieden an der Oberfläche tierischer Organe.*
Biochem. Zeitsch., **59**, 195.

LOCHHEAD, A. C., AND CRAMER, W. [1907]. *On the Phosphorus Percentage of Various Samples of Protagon.*
Biochem. J., **2**, 350.

LOENING, H., UND THIERFELDER, H. [1910]. *Über das Cerebron.*
Zeitsch. physiol. Chem., **68**, 464.

LOENING, H., UND THIERFELDER, H. [1911]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., **74**, 282.

LOENING, H., UND THIERFELDER, H. [1912]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., **77**, 202.

LOEWE, S. [1912]. *Zur physikalischen Chemie der Lipoide. Beziehungen der Lipoide zu den Farbstoffen.*
Biochem. Zeitsch., **42**, 150.

LOEWE, S. [1912, 1]. *Zur physikalischen Chemie der Lipoide. Die Beziehungen der Lipoide zu anderen organischen Substanzen (Narkoticis, Hypnoticis).*
Biochem. Zeitsch., 42, 190.

LOEWE, S. [1912, 2]. *Zur physikalischen Chemie der Lipoide. Diffusion in Lipoiden.*
Biochem. Zeitsch., 42, 205.

LOEWE, S. [1912, 3]. *Zur physikalischen Chemie der Lipoide. Die Eigenschaften von Lipoidlösungen in organischen Lösungsmittel.*
Biochem. Zeitsch., 42, 207.

LONG, J. H. [1906]. *On the Extraction of Fat from Fæces and the Occurrence of Lecithin.*
J. Am. Chem. Soc., 28, 704.

LONG, J. H. [1908]. *Observations on the Stability of Lecithin.*
J. Am. Chem. Soc., 30, 881.

LONG, J. H., AND GEPHART, F. [1908]. *On the Behaviour of Emulsions of Lecithin with Metallic Salts and certain Non-electrolytes.*
J. Am. Chem. Soc., 30, 895.

LONG, J. H., AND GEPHART, F. [1908, 1]. *On the Behaviour of Lecithin with Bile Salts and the Occurrence of Lecithin in Bile.*
J. Am. Chem. Soc., 30, 1312.

LONG, J. H., AND JOHNSON, W. A. [1906]. *The Phosphorus Content of Feces Fat.*
J. Am. Chem. Soc., 28, 1499.

LÜDECKE [1905]. *Zur Kenntnis der Glyzerinphosphorsäure und des Lecithins.*
Inaug. Diss. Munich.

MACARTHUR, C. J. [1914]. *Brain Cephalin; Distribution of the Nitrogenous Hydrolysis Products of Cephalin.*
J. Am. Chem. Soc., 36, 2397.

MACARTHUR, C. G., AND BURTON, L. V. [1916]. *Brain Cephalin. Fatty Acids.*
J. Am. Chem. Soc., 38, 1375.

MACARTHUR, C. G., AND LUCKETT, C. L. [1915]. *Lipins in Nutrition.*
J. Biol. Chem., 20, 161.

MCCLENAHAN, F. M. [1913]. *The Development of Fat in the Black Walnut (Juglans Nigra).*
J. Am. Chem. Soc., 35, 485.

MCCOLLUM, E. V., AND DAVIS, M. [1913]. *The Necessity of Certain Lipins in the Diet during Growth.*
J. Biol. Chem., 15, 167.

MCCOLLUM, E. V., HALPIN, J. G., AND DRESCHER, A. H. [1912]. *Synthesis of Lecithin in the Hen and the Character of the Lecithins Produced.*
J. Biol. Chem., 13, 219.

MACKENZIE-WALLIS, R. L., AND SCHÄLBERG, H. A. [1910]. *On Chylous and Pseudochylous Ascites.*
Q. J. Med., 3, 301; 4, 153.

MACLEAN, H. [1908]. *Weitere Versuche zur quantitativen Gewinnung von Cholin aus Lecithin.*
Zeitsch. physiol. Chem., 55, 360.

MACLEAN, H. [1908, 1]. *On the Nitrogen-containing Radicle of Lecithin and other Phosphatides.*
Biochem. J., 4, 38.

MACLEAN, H. [1908, 2]. *Versuche über den Cholingehalt des Herzmuskellecithins.*
Zeitsch. physiol. Chem., 57, 296.

MACLEAN, H. [1909]. *Untersuchungen über Eigelb-Lecithin.*
Zeitsch. physiol. Chem., 59, 223.

MACLEAN, H. [1909, 1]. *On the Nitrogen-containing Radicles of Lecithin and other Phosphatides.*
Biochem. J., 4, 240.

MACLEAN, H. [1909, 2]. *On the Occurrence of a Monaminodiphosphatide Body in Egg-yolk.*
Biochem. J., 4, 168.

MACLEAN, H. [1912]. *The Extraction and Purification of Tissue Phosphatides.*
J. Physiol., 45; Proc., p. xiii.

MACLEAN, H. [1912, 1]. *On Carnaubon.*
J. Physiol., 45; Proc., p. xviii.

MACLEAN, H. [1912, 2]. *The Phosphatides of the Kidney.*
Biochem. J., 6, 333.

MACLEAN, H. [1912, 3]. *On the Purification of Phosphatides.*
Biochem. J., 6, 355.

MACLEAN, H. [1913]. *Die Phosphatide des Herzens und anderer Organe.*
Biochem. Zeitsch., 57, 132.

MACLEAN, H. [1914]. *A Simple Method for the Preparation of Lecithin.*
J. Path. Bact., 18, 490.

MACLEAN, H. [1914, 1]. *On the so-called "Acetone-soluble Phosphatides."*
Biochem J., 8, 453.

MACLEAN, H. [1915]. *The Composition of "Lecithin" together with Observations on the Distribution of Phosphatides in the Tissues and Methods for their Extraction and Purification.*
Biochem. J., 9, 351.

MACLEAN, H., AND GRIFFITHS, W. J. [1920]. *"Cuorin."*
Biochem. J., 14, 615.

MACLEAN, H., AND WILLIAMS, O. T. [1909]. *On the Nature of the so-called Fat of Tissues and Organs.*
Biochem. J., 4, 455.

MCLEAN, J. [1916]. *Thromboplastic Action of Cephalin.*
Am. J. Physiol., 41, 250.

MALENGREAU, F., UND PRIGENT, G. [1911]. *Über die Geschwindigkeit der Hydrolyse der Glycerinphosphorsäure.*
Zeitsch. physiol. Chem., 73, 68.

MALENGREAU, F., UND PRIGENT, G. [1912]. *Über Hydrolyse und Konstitution des Lecithins.*
Zeitsch. physiol. Chem., 77, 107.

MANASSE, P. [1895]. *Ueber zuckerabspaltende, phosphorhaltige Körper in Leber und Nebenniere.*
Zeitsch. physiol. Chem., 20, 478.

MANASSE, A. [1906]. *Über den Gehalt des Eidotters an Lecithin.*
Biochem. Zeitsch., 1, 246.

MARIE, T. [1896]. *Sur les formules des acides cérotique et mélissique extraits de la cire d'abeilles.*
Bull. Soc. chim., 15, 565.

MARK, H. [1907]. *Ueber das Jecorin.*
Inaug. Diss. Leipzig.

MATTHES, H., UND SANDERR, H. [1908]. *Ueber Lorbeerfett insbesondere über die unverseifbaren Bestandteile desselben.*
Arch. Pharm., 246, 165.

MAXWELL, W. [1891]. *On the Methods of Estimation of the Fatty Bodies in Vegetable Organisms.*
Am. Chem. J., 13, 13.

MAXWELL, W. [1891, 1]. *On the Behaviour of the Fatty Bodies and the Rôle of the Lecithins during Normal Germination.*
Am. Chem. J., 13, 16.

MAYER, A., ET SCHAEFFER, G. [1913]. *Recherches sur la constance lipocytique. Teneur des tissus en lipoides phosphorés.*
Compt. rend., 157, 156.

MAYER, A., ET SCHAEFFER, G. [1913, 1]. *Recherches sur la Teneur des Tissus en Lipoides Existence possible d'une constance lipocytique.*
J. Physiol. Path. gen., xv, 510.

MAYER, A., ET SCHAEFFER, G. [1913, 2]. *Teneur des tissus en phosphore lie aux lipoides. Constance de cette teneur.*
J. Physiol. Path. gen., xv, 555.

MAYER, A., ET SCHAEFFER, G. [1913, 3]. *Teneur en lipoides des globules et du serum sanguin.*
J. Physiol. Path. gen., xv, 773.

MAYER, A., ET SCHAEFFER, G. [1914]. *Variations de la teneur des tissus en lipoides et en eau au cours de l'inanition absolue.*
J. Physiol. Path. gen., xvi, 1.

MAYER, A., ET SCHAEFFER, G. [1914, 1]. *Recherches sur les constantes cellulaires teneur des Cellules en eau.* I. *Discussion theoriques d'eau constante cellulaire.*
J. Physiol. Path. gen., xvi, 16.

MAYER, A., ET SCHAEFFER, G. [1914, 2]. II. *Rapport entre la teneur des cellules en lipoides et leur teneur en eau.*
J. Physiol. Path. gen., xvi, 23.

MAYER, A., ET SCHAEFFER, G. [1914, 3]. *Variations de la teneur des tissus en lipoides et en eau au cours de l'inanition absolue.*
J. Physiol. Path. gen., xvi, 204.

MAYER, A., ET TÉRROINE, E. F. [1907]. *Recherches sur les complexes colloïdaux d'albuminoïdes et de lipoïdes.*
Compt. rend. soc. biol., 62, 398.

MAYER, P. [1906]. *Über die Spaltung der lipoiden Substanzen durch Lipase und über die optischen Antipoden des natürlichen Lecithins.*
Biochem. Zeitsch., 1, 39.

MAYER, P. [1906, 1]. *Ueber Lecithinzucker und Jekorin sowie ueber das physikalisch-chemische Verhalten des Zuckers in Blut.*
Biochem. Zeitsch., 1, 81.

MAYER, P. [1908]. *Zur Chemie des Lecithins.*
Biochem. Zeitsch., 8, 199.

MEIGS, E. B., BLATHERWICK, N. R., AND CAREY, C. A. [1919]. *Contributions to the Physiology of Phosphorus and Calcium Metabolism as related to Milk Secretion.*
J. Biol. Chem., 37, 1.

MEINERTZ, J. [1905]. *Zur Chemie der Phosphorleber.*
Zeitsch. physiol. Chem., 44, 371.

MEINERTZ, J. [1905, 1]. *Zur Kenntniss des Jecorins.*
Zeitsch. physiol. Chem., 46, 376.

MERLIS, M. [1897]. *Über die Zusammensetzung der Samen und der etiolierten Keimpflanzen von Lupinus angustifolius.*
Landw. Versuchstat., 48, 419.

MEYER, H., BROD, L., UND SOYKA, W. [1913]. *Über die Lignocerinsäure.*
Monats. Chem., 34, 1113.

MEYERHOF, O. [1923]. *Ueber ein neues autoxydablen System der Zelle (die Rolle der Sulfhydrilgruppe als Sauerstoff träger).*
Pfluger's Archiv ges. Physiol., 199, 531.

MEYERHOF, O. [1924]. *Chemical Dynamics of Life Phenomena.*
(Lippincott & Co.)

MICHAELIS, L., UND PINCUSSOHN, L. [1906]. *Zur Theorie der Schutzkolloide.*
Biochem. Zeitsch., 2, 521.

MICHAELIS, L., UND RONA, P. [1907]. *Über die Löslichkeitsverhaltnisse von Albumosen und Fermenten mit Hinblick auf ihre Beziehungen zu Lecithin und Mastix.*
Biochem. Zeitsch., 4, 11.

MIESCHER, F. [1871]. *Ueber die chemische Zusammensetzung der Eiterzellen.*
Hoppe-Seyler Med. Chem. Unters., 4, 441.

MILLS, C. A. [1921]. *Chemical Nature of Tissue Coagulins.*
J. Biol. Chem., 46, 135.

MILLS, C. A. [1921, 1]. *The Action of Tissue Extracts in the Coagulation of the Blood.*
J. Biol. Chem., 46, 167.

MINAMI, D. [1912]. *Über den Einfluss des Lecithins und der Lipoide auf die Diastase (Amylase).*
Biochem. Zeitsch., 39, 355.

MORUZZI, G. [1908]. *Versuche zur quantitativen Gewinnung von Cholin und Lecithin.*
Zeitsch. physiol. Chem., 55, 352.

MÜLLER, — [1858]. *Ueber die chemischen Bestandtheile des Gehirns.*
Ann. Chem. Pharm., 105, 361.

MULON, P. [1903]. *Note sur une localisation de la lécithine dans les capsules surrénales du cobaye.*
Compt. rend. Soc. Biol., 55, 82.

NERKING, J. [1908]. *Die Verteilung des Lecithins im tierischen Organismus.*
Biochem. Zeitsch., 10, 193.

NERKING, J. [1910]. *Zur Methodik der Lecithinbestimmung.*
Biochem. Zeitsch., 23, 262.

NERKING, J., UND HAENSEL, E. [1908]. *Die Lecithingehalt der Milch.*
Biochem. Zeitsch., 13, 348.

NEUBERG, C., UND KRETSCHMER, E. [1911]. *Weiteres über künstliche Darstellung von Kohlenhydrat phosphorsäureestern und Glycerinphosphorsäure.*
Biochem. Zeitsch., 36, 5.

NEUBERG, C., UND TIR, L. [1911]. *Über zuckerfreie Hefegärungen.*
Biochem. Zeitsch., 32, 223.

NEUMANN, A. [1902]. *Einfache Veraschungsmethode (Saüregemisch-Veraschung) und Vereinfachte Bestimmungen von Eisen, Phosphorsäure, Salzsaüre und anderen Aschenbestandtheilen unter Benutzung dieser Saüregemisch-Veraschung.*
Zeitsch. physiol. Chem., 37, 115.

NEUMANN, A. [1904]. *Nachträge zur "Saüregemisch-Veraschung" und zu den an diese angeknüpften Bestimmungmethoden.*
Zeitsch. physiol. Chem., 43, 32.

NEUMANN, J. [1908]. *Ueber Beeinflussung der tryptischen Verdauung durch Fettstoffe.*
Berl. klin. Woch., No. 45, 2066.

NJEGOVAN, V. [1910], *Zur Bestimmung der Phosphatide in der Milch.*
Biochem. Zeitsch., 29, 491.

NJEGOVAN, V. [1911]. *Beiträge zur Kenntniss der pflanzlichen Phosphatide.*
Zeitsch. physiol. Chem., 76, 1.

NJEGOVAN, V. [1913]. *Enthält die Milch Phosphatide ?*
Biochem. Zeitsch., 54, 78.

NOLL, A. [1899]. *Ueber die quantitativen Beziehungen des Protagons zum Nervenmark.*
Zeitsch. physiol. Chem., 27, 370.

OFFER [1904]. Quoted from Bang [1911].

OSBORNE, T. B., AND MENDEL, L. B. [1912]. *Feeding Experiments with Fat-free Food Mixtures.*
J. Biol. Chem., 12, 81.

OSBORNE, T. B., AND MENDEL, L. B. [1913]. *The Relation of Growth to the Chemical Constituents of the Diet.*
J. Biol. Chem., 15, 311.

OSBORNE, T. B., AND MENDEL, L. B. [1913, 1]. *The Influence of Butter Fat on Growth.*
J. Biol. Chem., 16, 423.

OSBORNE, T. B., AND MENDEL, L. B. [1916]. *The Stability of the Growth-promoting Substance in Butter-fat.*
J. Biol. Chem., 24, 37.

OSBORNE, T. B., AND WAKEMAN, A. J. [1915]. *Some New Constituents of Milk.* I. *Phosphatides.*
J. Biol. Chem., 21, 539.

OSBORNE, T. B., AND WAKEMAN, A. J. [1916]. *Distribution of Phosphatides of Milk.*
J. Biol. Chem., 28, 1.

OTOLSKI, S. W. [1907]. *Das Lecithin des Knochenmarks.*
Biochem. Zeitsch., 4, 124.

OTTO, J. G. [1885]. *Ueber den Gehalt des Blutes an Zucker und reducirender Substanz unter verschiedenen Umständen.*
Arch. f. Ges. Physiol., 35, 467.

OVERTON, E. [1900]. *Studien ueber die Aufnahme der Anilinfarben durch die lebende Zelle.*
Jahrb. f. wissensch. Bot., 34, 669.

OVERTON, E. [1901]. *Studien über die Narkose.*
(Jena.)

PAAL, C., UND OEHME, H. [1913]. *Die Hydrogenisation des Ei-Lecithins.*
Ber., 46, 1297.

PALLADIN, W., UND STANEWITSCH, E. [1910]. *Die Abhängigkeit der Pflanzenatmung von den Lipoiden.*
Biochem. Zeitsch., **26**, 351.

PARCUS, E. [1881]. *Ueber einige neue Gehirnstoffe.*
J. pr. Chem., **24**, 310.

PARHON, C., DUMITRESCO, G., AND NISSIPESCO, C. [1909]. *Note sur les lipoides des ovaires.*
Compt. rend. Soc. Biol., **66**, 650.

PARKE, J. L. [1867]. *Ueber die chemische Constitutions des Eidotters.*
Hoppe-Seyler Med. Chem. Unters., **2**, 209.

PARNAS, J. [1909]. *Über Kephalin.*
Biochem. Zeitsch., **22**, 411.

PARNAS, J. [1913]. *Über die gesätligte Fettsäure des Kephalins.*
Biochem. Zeitsch., **56**, 17.

PARROZZANI, A. [1910]. *Der Gehalt an organischen Phosphor und das Verhältnis zwischen Amidstickstoff und den übrigen nicht eiweissartigen Formen des Stickstoffs in reifen Samen.*
Chem. Zentr., i, 545.

PATTA, A. [1912]. *Neue Untersuchungen über dem Einfluss von Lecithin auf die Stickstoff und Phosphorbilanz.*
Chem. Zentr., ii, 939.

PEARSON, A. L. [1914]. *A Comparison between the Molecular Weights of Protagon and of the Phosphatide and Cerebrosides obtainable from it.*
Biochem. J., **8**, 616.

PETROWSKY, D. [1873]. *Zusammensetzung der grauen und der weissen Substanz des Gehirns.*
Arch. f. Gesamt. Physiol., **7**, 367.

PINKUS, S. N. [1901]. *The Precipitation of the Proteids with Anhydrous Sodium Sulphate.*
J. Physiol., **27**, 57.

PLIMMER, R. H. A., AND SCOTT, F. H. [1909]. *The Transformations in the Phosphorus Compounds in the Hen's Egg during Development.*
J. Physiol., **38**, 247.

PLIMMER, R. H. A. [1913]. *The Metabolism of Organic Phosphorus Compounds. Their Hydrolysis by the Action of Enzymes.*
Biochem. J., **7**, 43.

PORGES, O., AND NEUBAUER, E. [1907]. *Physikalisch-chemische Untersuchungen über das lecithin und cholesterin.*
Biochem. Zeitsch., **7**, 152.

POSNER, E. R., AND GIES, W. J. [1905]. *A Further Study on Protagon.*
Am. J. Physiol., **13**, xxxv.

POSNER, E. R., AND GIES, W. J. [1905, 1]. *Is Protagon a Mechanical Mixture of Substances or a Definite Chemical Compound ?*
J. Biol. Chem., **1**, 59.

POUGET, I., ET CHOUCHAK, D. [1909]. *Dosage colorimétrique de l'acide phosphorique.*
Bull. Soc. Chim., v, 104.

POWER, F. B., AND TUTIN, F. [1905]. *The Relation between Natural and Synthetical Glycerylphosphoric Acids.*
J. Chem. Soc., **87**, 249.

PRIANISCHNIKOW, D. [1895]. *Zur Kenntniss der Keimungsvorgänge bei Vicia Sativa.*
Landw. Versuchstat., **45**, 247.

PRYDE, J., AND HUMPHREYS, R. W. [1924]. *The Methylation of the Cerebrosides of Ox-brain.*
Biochem. J., **18**, 661.

QUASTEL, J. H. [1926]. *Dehydrogenations produced by Resting Bacteria.* IV. *A Theory of the Mechanisms of Oxidations and Reductions* in vivo.
Biochem. J., **20**, 166.

RENALL, M. H. [1913]. *Über den stickstoffhaltigen Bestandteil des Kephalins.*
Biochem. Zeitsch., **55**, 296.

RIEDEL, J. D. [1905]. *Verfahren zur Darstellung eines iodhaltigen Präparates aus Lecithin.*
D.R.P., 155629.

RIEDEL, J. D. [1912]. *Zur Kenntniss des Eigelblecithins.*
Chem. Zentr., i, 1794.

RIEDEL, J. D. [1913]. *Zur Kenntniss des Eigelblecithins*
Chem. Zentr., i, 2172.

RIEDEL, J. D. [1914]. *Zur Kenntniss des Eigelblecithins.*
Chem. Zentr., i, 1896.

RIESSER, O., UND THIERFELDER, H. [1912]. *Ueber das Cerebron.*
Zeitsch. physiol. Chem., 77, 508.

RITTER, F. [1914]. *Zur Kenntniss des Hydro-lecithins.*
Ber., 47, 530.

ROAF, H. E., AND EDIE, E. S. [1905]. *Preparation and Estimation of Lecithin.*
Thompson, Yates and Johnston, Lab. Rep., Liverpool, 6, 201.

ROBERTSON, T. B. [1913]. *On the Nature of the Autocatalyst of Growth.*
Arch. Entwickelungsmech. Org., 37, 497.

ROBERTSON, T. B. [1916]. *Influence of Lecithin on the Growth of the White Mouse.*
J. Biol. Chem., 25, 647.

ROBERTSON, T. B., AND BURNETT, T. C. [1913]. *The Influence of Lecithin and Cholesterin upon the Growth of Tumours.*
J. Exp. Med., 17, 344.

ROBERTSON, T. B., AND CUTLER, E. [1916]. *Influence of the Administration of Egg Lecithin and of Cholesterol to the Mother, on the Growth of Suckling Mice.*
J. Biol. Chem., 25, 663.

ROGIER ET FIORE [1913]. *Untersuchung über die krystallinischen Glycerophosphate.*
Chem. Zentr., i, 1330.

RÖHMANN, F. [1905]. *Ueber das lanocerin, einen neuen Bestandteil des Wollfetts.*
Centr. Physiol., 19, 317.

ROLLETT, A. [1909]. *Über die Alkoholyse des Lecithins.*
Zeitsch. physiol. Chem., 61, 210.

ROSCOE, H. E. [1880]. *Letter to Gamgee.*
Proc. Roy. Soc., 30, 113.

ROSCOE, H. E. [1880, 1]. *On the Absence of Potassium in Protagon Prepared by Dr. Gamgee.*
Proc. Roy. Soc., 30, 365.

ROSENBLOOM, J. [1911]. *On the Forms in which Lipins are Combined in Cells.*
Studies in Cancer and allied subjects. G. Crocker Research Fund, Columbia University. Vol. III, 260.

ROSENBLOOM, J. [1913]. *A New Method for Drying Tissues and Fluids.*
J. Biol. Chem., 14, 27.

ROSENBLOOM, J. [1913, 1]. *The Lipins of the Heart Muscle of the Ox.*
J. Biol. Chem., 14, 291.

ROSENHEIM, O. [1906]. *On the Preparation of Cholesterin from Brain.*
J. Physiol., 34, 104.

ROSENHEIM, O. [1909]. *Proposals for the Nomenclature of the Lipoids.*
Biochem. J., 4, 331.

ROSENHEIM, O. [1913]. *The Galactosides of the Brain.*
Biochem. J., 7, 604.

ROSENHEIM, O. [1913, 1]. *The Galactosides of the Brain and their Constitution.*
Trans. Int. Congr. Med., sect. 2, pt. 2, 123.

ROSENHEIM, O. [1914]. *The Galactosides of the Brain. The Preparation of Phrenosin and Kerasin by the Pyridine Method.*
Biochem. J., 8, 110.

ROSENHEIM, O. [1914, 1]. *The Galactosides of the Brain. Liquid Crystals and the Melting-point of Phrenosin.*
Biochem. J., 8, 121.

ROSENHEIM, O. [1916]. *The Galactosides of the Brain. The Constitution of Phrenosin and Kerasin.*
Biochem. J., 10, 142.

ROSENHEIM, O., AND MACLEAN, H. [1915]. *Lignoceric Acid from Carnaubon.*
Biochem. J., 9, 103.

ROSENHEIM, O., AND TEBB, M. C. [1907]. *The Non-existence of "Protagon" as a Definite Chemical Compound.*
J. Physiol., 36, 1.

ROSENHEIM, O., AND TEBB, M. C. [1908]. *On So-called "Protagon."*
Q.J. Exp. Physiol., 1, 297.

ROSENHEIM, O., AND TEBB, M. C. [1908, 1]. *The Optical Activity of So-called "Protagon."*
J. Physiol., 37, 341.

ROSENHEIM, O., AND TEBB, M. C. [1908, 2]. *Further Proofs of the Non-existence of "Protagon" as a Definite Chemical Compound.*
J. Physiol., 37, Proc., I.

ROSENHEIM, O., AND TEBB, M. C. [1908, 3]. *On a New Physical Phenomenon observed in Connection with the Optical Activity of So-called "Protagon."*
J. Physiol., 37, 348.

ROSENHEIM, O., AND TEBB, M. C. [1909]. *The Non-existence of "Protagon" as a Definite Chemical Compound.*
Q.J. Exp. Physiol., 2, 317.

ROSENHEIM, O., AND TEBB, M. C. [1909, 1]. *The Lipoids of the Brain. Sphingomyelin.*
J. Physiol., 38, Proc., LI.

ROSENHEIM, O., AND TEBB, M. C. [1909, 2]. *On the Lipoids of the Adrenals.*
J. Physiol., 38, Proc., LIV.

ROSENHEIM, O., AND TEBB, M. C. [1910] *Die Nicht-Existenz des sogenannten "Protagons" im Gehirn.*
Biochem. Zeitsch., 25, 151.

ROSENHEIM, O., AND TEBB, M. C. [1910, 1]. *The Lipoids of the Brain. A New Method for the Preparation of the Galactosides and of Sphingomyelin.*
J. Physiol. Chem., 41, Proc., I.

RUMPF, F. [1913]. *Über den Einfluss der Lipoide auf die Gerinnung des Blutes.*
Biochem. Zeitsch., 55, 101.

RUPPEL, W. G. [1895]. *Zur Kenntniss des Protagons.*
Zeitsch. Biol., 31, 86.

SAKAKI, C. [1913]. *Über einige Phosphatide aus der menslichen Placenta.*
Biochem. Zeitsch., 49, 317.

SAKAKI, C. [1913, 1]. *Über einige Phosphatide aus der menslichen Placenta*
Biochem. Zeitsch., 49, 326.

SAMMARTINO, U. [1921]. *Ueber die Chemie der Lunge.*
Biochem. J., 124, 234.

SANO, M. [1922]. *The Phosphatides of the Fish Sperm.*
J. Biochem., Tokyo, 1, 1; Physiol. Abs., 7, 160.

SANO, M. [1922, 1]. *Optical Properties of Sphingomyelin.*
J. Biochem., Tokyo, 1, 17; Physiol. Abs., 7, 160.

SCHAUMANN, H. [1911]. *Further Contributions to the Etiology of Beri-beri.*
Trans. Soc. Trop. Med., 5, 59.

SCHLAGDENHAUFFEN ET REEB, M. M. [1902]. *Sur la présence de la lécithine dans les végétaux.*
Compt. rend., 135, 205.

SCHMIDT, A., UND MÜLLER, F. [1898]. *Ueber Herkunft und Chemische Natur der Myelinformen des Sputums.*
Berl. klin. Woch., 35, 73.

SCHRYVER, S. B. [1906]. *Studies in the Chemical Dynamics of Animal Nutrition.*
Biochem. J., 1, 123.

SCHULZE, E. [1893]. *Ueber einige stickstoffhaltige Bestandtheile der Keimlinge von Vicia Sativa.*
Zeitsch. physiol. Chem., 17, 193.

SCHULZE, E. [1894]. *Ueber die Bestimmung das Lecithingehaltes der Pflanzensamen.*
Zeitsch. physiol. Chem., 20, 225.

SCHULZE, E. [1897]. *Ueber das pflanzliche Lecithin.*
Chem. Zeit., 21, 374.

SCHULZE, E. [1898]. *Über den Lecithingehalt einiger Pflanzensamen und einiger Ölkuchen.*
Landwirt. Versuchstat., 49, 203.

SCHULZE, E. [1904]. *Ueber die Bestimmung des Lecithins in den Pflanzen.* Chem. Zeit., **28**, 751.

SCHULZE, E. [1907]. *Über den Phosphorgehalt einiger aus Pflanzensamen dargestellter Lecithinpräparate.* Zeitsch. physiol. Chem., **52**, 54.

SCHULZE, E. [1908]. *Über die zur Darstellung von Lecithin verwendbaren Methoden.* Zeitsch. physiol. Chem., **55**, 338.

SCHULZE, E. [1908, 1]. *Über pflanzliche Phosphatide.* Chem. Zeit., **32**, 981.

SCHULZE, E., UND FRANKFURT, S. [1894]. *Über den Lecithingehalt einiger vegetabilischer Substanzen.* Landwirt. Versuchstat., **43**, 307.

SCHULZE, E., UND LIKIERNIK, A. [1891]. *Ueber das Lecithin der Pflanzensamen.* Zeitsch. physiol. Chem., **15**, 405.

SCHULZE, E., UND PFENNIGER, U. [1911]. *Untersuchungen über die in den Pflanzevorkommenden Betaine.* Zeitsch. physiol. Chem., **71**, 174.

SCHULZE, E., UND STEIGER, E. [1889]. *Ueber den Lecithingehalt der Pflanzensamen.* Zeitsch. physiol. Chem., **13**, 364.

SCHULZE, E., UND STEIGER, E. [1889, 1]. *Untersuchungen über die Stickstoffreien Reservestoffe der Samen von Lupinus luteus und über die Umwandlung derselben während des Keimungs-prozesses.* Lands. Versuchstat., **36**, 391.

SCHULZE, E., STEIGER, E., UND MAXWELL, W. [1891]. *Untersuchungen über die chem. ische Zusammensetzung einiger Leguminosen samen.* Landw. Versuchstat., **39**, 269.

SCHULZE, E., UND TRIER, G. [1911]. *Untersuchungen über die in den Pflanzen vorkommenden Betaine.* Zeitsch. physiol. Chem., **76**, 258.

SCHULZE, E., UND WINTERSTEIN, E. [1903]. *Beiträge zur Kenntniss der aus Panzen darstellbaren Lecithine.* Zeitsch. physiol. Chem., **40**, 101.

SCHULZE, E., UND WINTERSTEIN, E. [1910]. *Phosphatide.* Handb. biochem. Arbeitsmeth (Abderhalden), **2**, 256.

SCHUMOFF-SIMANOWSKI, C., UND SIEBER, N. [1906]. *Das Verhalten des Lecithins zu feltspaltenden Fermenten.* Zeitsch. physiol. Chem., **49**, 50.

SCOTT, E. L. [1916]. *A Study of a Lecithin-glucose Preparation.* Am. J. Physiol., **40**, 145.

SEDLMAYR, [1903]. *Das Lecithin der Hefe.* Zeitsch. f. d. ges. Brauwesen, **26**, 381, 397.

SERANO, C., UND PALOZZI, A. [1911]. *Über die im Eidotter enthaltene Lipoide.* Chem. Centr., ii, 772.

SERANO, C., UND PALOZZI, A. [1915]. Rass. di. clin. terap., xiv, 299.

SHINGU, R. [1922]. *The Action of the Lipoids of the Spleen in Accelerating Coagulation of the Blood.* Mitt. Med. Fak. Kars., Univ. Tokyo, **29**, 1; Physiol. Abs., **9**, 375.

SHOREY, E. C. [1898]. *The Lecithin of Sugar-cane.* J. Am. Chem. Soc., **20**, 113.

SIEBER, N. [1909]. *Die Lipoide der Lunge.* Zeitsch. physiol. Chem., **62**, 250.

SIEGFRIED, M., UND MARK, H. [1905]. *Zur Kenntniss des Jecorins.* Zeitsch. physiol. Chem., **46**, 492.

SIGNORELLI, E. [1910]. *Über die oxydations prozesse der Lipoide des Rückenmarks.* Biochem. Zeitsch., **29**, 25.

SLOWTZOFF, P. [1906]. *Die Wirkung des Lecithins auf den Stoffwechsel.* Bei. Chem. physiol. Path., **8**, 370.

SMITH, J. LORRAIN, AND MAIR, W. [1910]. *On a Method of Isolating Cholesterin and Cerebrosides from Brain by means of Saponification with Barium Hydrate and Methyl Alcohol.*
J. Path. Bact., 15, Proc., 122.

SMITH, J. LORRAIN, AND MAIR, W. [1910, 1]. *The Effect of Glycerin on the Clearing-point of Cholesterin and Cerebrosides.*
J. Path. Bact., 15, Proc., 122.

SMITH, J. LORRAIN, AND MAIR, W. [1910, 2]. *An Electric Hot Stage for the Microscope.*
J. Path. Bact., 15, Proc., 123.

SMITH, J. LORRAIN, AND MAIR, W. [1911]. *On a Method of Quantitative Analysis of Tissue Lipoids with a Preliminary Note on Degeneration in the Brain.*
J. Path. Bact., 16, Proc., 131.

SMITH, J. LORRAIN, AND MAIR, W. [1912]. *The Development of Lipoids in the Brain of the Puppy.*
J. Path. Bact., 17, Proc., 123.

SMITH, J. LORRAIN, AND MAIR, W. [1913]. *The Lipoids of the White and Grey Matter of the Human Brain at Different Ages.*
J. Path. Bact., 17, Proc., 418.

SMITH, J. LORRAIN, AND MAIR, W. [1913, 1]. *On a Method of Analysis of Brain Lipoids.*
J. Path. Bact., 17, 609.

SMOLENSKI, K. [1909]. *Zur Kenntniss der aus Weizenkeimen darstellbaren Phosphatide.*
Zeitsch. physiol. Chem., 58, 522.

STARKENSTEIN, E. [1911]. *Über die Unabhängigkeit der Diastase wirkung von den Lipoiden.*
Biochem. Zeitsch., 33, 423.

STASSANO, H., ET BILLON, F. [1902]. *Contribution à la connaissance de l'action de la lécithine sur les éléments figurés du sang.*
Compt. rend., 134, 318.

STEEL, M., AND GIES, W. J. [1907]. *On the Chemical Nature of Paranucleoprotagon, a New Product from Brain.*
Am. J. Physiol., 20, 378.

STELLWAG, A. [1890]. *Die Zusammensetzung der Futtermittelfette.*
Landw. Versuchstat., 37, 135.

STEPP, W. [1909]. *Versuche über Fütterung mit lipoidfreier Nahrung.*
Biochem. Zeitsch,, 22, 452.

STEPP, W. [1911]. *Experimentelle Untersuchungen über die Bedeutung der Lipoide fur die Ernährung.*
Zeitsch. Biol., 57, 135.

STEPP, W. [1913]. *Fortgesetzte Untersuchungen über die Unentbehrlichkeit der Lipoid-für das Leben. Über das Verhalten der lebenswichtigen Stoffe zu den Lipoidextrake tionsmitteln.*
Zeitsch. Biol., 62, 405.

STERN, M., UND THIERFELDER, H. [1907]. *Über die Phosphatide des Eigelbs.*
Zeitsch. physiol. Chem., 53, 370.

STOKLASA, J. [1895]. *Die Assimilation des Lecithins durch die Pflanze.*
Sitz. ber. K.K. Akad. Wissensch., Abt. I, 712.

STOKLASA, J. [1897]. *Zur Kenntniss des Phosphors in der Frauen- und Kuhmilch.*
Zeitsch. physiol. Chem., 23, 343.

STRECKER, A. [1862]. *Ueber einige neue Bestandtheile der Schweinegalle.*
Ann. Chem. Pharm., 123, 353.

STRECKER, A. [1868]. *Ueber das Lecithin.*
Ann. Chem. Pharm., 148, 77.

STROMER, F., UND FALLADA, O. [1906]. *Über die chemische Zusammensetzung des Samens der Zuckerrube (Beta vulgaris).*
Chem. Centr., i., 1440.

STRUVE, H. [1900]. *Zur Bedeutung der Florence'schen Reaction.*
Zeitsch. analyt. Chem., 39, 1.

STUBER, B. [1913]. *Ueber Blutlipoide und Phagocytose I.*
Biochem. Zeitsch., 51, 211.

STUTZER, A. [1908]. *Untersuchungen über den Gehalt vegetablischer Stoffe an Stickstoff, Phosphor und Schwefel in organischer Bindung.*
Biochem. Zeitsch., 7, 471.

TAIT, J., AND CAMPBELL, W. [1914]. *The Lipoid-content of Peritoneal Epithelium.*
Q.J. Exp. Physiol., 8, 395.

TAIT, J., AND HEWITT, J. A. [1914]. *The Lipoid-content of Vascular Endothelium.*
Q.J. Exp. Physiol., 8, 391.

TAYLOR, A. E., AND MILLER, C. W. [1914]. *On the Estimation of Phosphorus in Biological Material.*
J. Biol. Chem., 18, 215.

TÉRROINE, É. F. [1911]. *Lecithin und diastasiche wirkungen.*
Biochem. Zeitsch., 35, 506.

TÉRROINE, É. F. [1914]. *L'existence d'une constante lipémique.*
J. de Physiol. et Path. gén., 16, 212.

TÉRROINE, É. F. [1914, 1]. *Le transport des graisses. Variations Lipocholestérinémiques au cours de l'inanition et de l'alimentation.*
J. de Physiol. et Path. gén., 16, 384.

THIERFELDER, H. [1890]. *Ueber die Identität des Gehirnzuckers mit Galactose.*
Zeitsch. physiol. Chem., 14, 209.

THIERFELDER, H. [1904]. *Über das Cerebron.*
Zeitsch. physiol. Chem., 43, 21.

THIERFELDER, H. [1905]. *Über das Cerebron.*
Zeitsch. physiol. Chem., 44, 366.

THIERFELDER, H. [1905, 1]. *Phrenosin and Cerebron.*
Zeitsch. physiol. Chem., 46, 521.

THIERFELDER, H. [1909]. *Handbuch der physiologisch und pathologischen-chemischen Analyse.*
(Hoppe-Seyler.) (Berlin.)

THIERFELDER, H. [1913]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., 85, 35.

THIERFELDER, H. [1914]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., 89, 236.

THIERFELDER, H. [1914, 1]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., 89, 248.

THIERFELDER, H. [1914, 2]. *Untersuchungen über die Cerebroside des Gehirns.*
Zeitsch. physiol. Chem., 91, 107.

THIERFELDER, H., AND KLENK, E. [1925]. *Versuche zur Darstellung des glucosamin haltigen Phosphatids von S. Fränkel und F. Kafka aus Gehirn.*
Zeitsch. physiol. Chem., 145, 220.

THIERFELDER, H., UND SCHULZE, O. [1915]. *Ein neus Verfahren zur Abtrennung von Äthanolamin (Colamin) aus Phosphatid hydrolysaten.*
Zeitsch. physiol. Chem., 96, 296.

THOMAS, A. [1915] *A Study of the Effects of certain Electrolytes and Lipoid Solvents upon the Osmotic Pressures and Viscosities of Lecithin Suspensions.*
J. Biol. Chem., 23, 359.

THOMAS, K., UND THIERFELDER, H. [1912]. *Über das cerebron.*
Zeitsch. physiol. Chem., 77, 511.

THUDICHUM, J. L. W. [1874]. *Researches on the Chemical Constitution of the Brain.*
Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, 3, 113.

THUDICHUM, J. L. W. [1876]. *Further Researches on the Chemical Constitution of the Brain.*
Reports of the Medical Officer of the Privy Council and Local Government Board. New Series, 8, 117.

THUDICHUM, J. L. W. [1878]. *Further Researches in Chemical Biology.*
Seventh Ann. Rep. of the Local Gov. Board. Suppt. containing the Report of the Medical Officer for 1877, p. 281.

THUDICHUM, J. L. W. [1879]. *Note and Experiments on the Alleged Existence in the Brain of a Body termed "Protagon."*
Ann. Chem. Med., 1, 254.

THUDICHUM, J. L. W. [1880]. *Further Researches on the Chemical Constitution of the Brain and of the Organoplastic Substances.*
Ninth Ann. Rep. of the Local Govt. Board. Suppt. containing the Report of the Medical Officer for 1879.

THUDICHUM, J. L. W. [1880, 1]. *On the Inorganic Bases and Salts which are Found in Combination with the Educts of the Brain.*
Proc. Roy. Soc., 30 [1880], 278; Ann. Chem. Med., 2 [1881], 163.

THUDICHUM, J. L. W. [1881]. *On Modern Text-books as Impediments to the Progress of Animal Chemistry.*
Ann. Chem. Med., 2, 183.

THUDICHUM, J. L. W. [1881, 1]. *Researches on the Chemical Constitution of the Non-phosphorised Group of the Nitrogenised Principles of the Brain.*
Ann. Chem. Med., 2, 1.

THUDICHUM, J. L. W. [1882]. *Ueber das phrenosin einen neuen stickstoffhaltigen phosphorfreien specifischen Gehirnstoff.*
J. pr. Chem., 25, 19.

THUDICHUM, J. L. W. [1883]. *On Further Researches on the Chemical Constitution of the Brain.*
Twelfth Ann. Rep. of the Local Govt. Board. Suppt. containing the Report of the Medical Officer for 1882, p. 221.

THUDICHUM, J. L. W. [1884]. *A Treatise on the Chemical Constitution of the Brain.*
Baillière, Tindal & Co., London.

THUDICHUM, J. L. W. [1896]. *Late Inquiries on some Immediate Principles of the Brain. The Progress of Medical Chemistry.*
(London.)

THUNBERG, T. [1909]. *Über katalytische Bescheunigung der Sauerstoffaufnahme der Muskelsubstanz.*
Zent. Physiol., 23, 625.

THUNBERG, T. [1910]. *Untersuchungen autoxydabler Substanzen und autoxydabler Systeme von physiologischen Interesse, I, II.*
Skand. Arch. f. Physiol., 24, 90.

THUNBERG, T. [1913]. *Eine Bemerkung zu der Mitteilung von Warburg and Meyerhof über die katalytische Beschleunigung der Sauerstoffaufnahme des Lecithins durch Eisensalze.*
Zeitsch. physiol. Chem., 87, 82.

THUNBERG, T. [1916]. *Untersuchungen über autoxydable Substanzen und Systeme von physiologischen Interesse.*
Skand. Arch. Physiol., 33, 228.

TOLMATSCHEFF [1867]. *Zur Analyse der Milch.*
Hoppe-Seyler's med. chem. Unters., 2, 272.

TÖPLER [1861]. *Vorkommen des Phosphor in fetten Oelen.*
Land. Versuchstat., 3, 85.

TORNANI, E. [1909]. *Ueber das Lecithin und andere Bestandteile des Eigelbs.*
Chem. Zentr., ii, 1149.

TRIER, G. [1911]. *Aminoäthyl alkohol, ein Produkt der Hydrolyse des "Lecithins" (Phosphatids) der Bohnensamen.*
Zeitsch. physiol. Chem., 73, 383.

TRIER, G. [1912]. *Über einfache Pflanzenbasen und ihre Beziehungen zum Aufbau der Eiweissstoffe und Lecithine.*
(Berlin.)

TRIER, G. [1912, 1]. *Über die Gewinnung von Aminoäthylalkohol aus Eilecithin.*
Zeitsch. physiol. Chem., 76, 496.

TRIER, G. [1912, 2]. *Über die Umwandlung von Aminoäthylalkohol (Colamin) in Cholin.*
Zeitsch. physiol. Chem. 80, 409.

TRIER, G. [1913]. *Über die nach den Methoden der Lecithindarstellung aus Pflanzensamen erhältlichen Verbindungen.*
Zeitsch. physiol. Chem., 86, 1.

TRIER, G. [1913, 1]. *Über die nach den Methoden der Lecithindarstellung aus Pflanzensamen erhältlichen Verbindungen. Vergleichende Hydrolyse von Eilecithin.*
Zeitsch. physiol. Chem., 86, 141.

TRIER, G. [1913, 2]. *Über die nach den Methoden der Lecithindarstellung aus Pflanzensamen erhältlichen Verbindungen. Hafersamen.*
Zeitsch. physiol. Chem., 86, 153.

TRIER, G. [1913, 3]. *Über die nach den Methoden des Lecithindarstellung aus Pflanzensamen erhältlichen Verbindungen. Erbsen, Schwarzkiefer, Reis.*
Zeitsch. physiol. Chem., 86, 407.

TUTIN, F., AND HANN, A. C. O. [1906]. *The Relation between Natural and Synthetical Glycerylphosphoric Acids.*
J. Chem. Soc., 89, 1749.

ULPIANI, C. [1901]. *Attività ottica della lecitina.*
Gaz. Chim. Ital., 31, ii, 47.

ULPIANI, C. [1901, 1]. *Optische Aktivität des Lecithins.*
Chem. Centr., ii, 192.

ULPIANI, C., AND LELLI, G. [1902]. *Su un nuovo proteide del cervello.*
Gaz. Chim. Ital., 32, 466.

VAN SLYKE, D. D. [1912]. *The Quantitative Determination of Aliphatic Amino-groups.*
J. Biol. Chem., 12, 275.

VAN SLYKE, D. D. [1913]. *The Gasometric Determination of Aliphatic Amino-nitrogen in Minute Quantities.*
J. Biol. Chem., 16, 121.

VAUQUELIN [1812]. *Analyse de la mati re cérébrale de l'hommet de quelques animaux.*
Ann. de Chim., 81, 37.

VERNON, H. M. [1912]. *Die Abhängigkeit der Oxydasewirkung von Lipoiden.*
Biochem. Zeitsch., 47, 374.

VERNON, H. M. [1913]. *Die Rolle der Oberflächenspannung und der Lipoide für die lebenden Zellen.*
Biochem. Zeitsch., 51, 1.

VERNON, H. M. [1914]. *Die Abhängigkeit der Oxydasewirkung von Lipoiden.*
Biochem. Zeitsch., 60, 202.

VIRCHOW, C. [1911]. *Zur Lecithinbestimmung.*
Chem. Zeit., 35, 913.

VOGELER, H. [1909]. *Untersuchungen über das Vorkommen von Phosphatiden in vegetabilischen und tierischen Stoffen.*
Biochem. Zeitsch., 17, 189.

WAKSMAN, S. A. [1918]. *Thromboplastic Action of Cephalin.*
Amer. J. Physiol., 46, 375.

WALDVOGEL [1903]. *Die fettige Degeneration.*
Centr. f. Stoffwech. u. Verdauungskrank., 4, 405.

WALDVOGEL UND TINTEMANN [1904]. *Die Natur der Phosphorvergiftung.*
Centr. Path., 15, 97.

WALDVOGEL UND TINTEMANN [1906]. *Zur Chemie des Jecorins.*
Zeitsch. physiol. Chem., 47, 129.

WALLERSTEIN, M. [1897]. *Die Veränderungen des Fettes während der Keimung und deren Bedeutung für die chemisch physiologischen Vorgänge der Keimung.*
Chem. Centr., 1, 63.

WARBURG, O. [1911]. *Ueber Beeinflussung der Sauerstoffatmung.*
Zeitsch. physiol. Chem., 70, 413.

WARBURG, O. [1912]. *Ueber Beziehung zwischen zellstructur und biochemischen Reaktionen.*
Pflüger's Arch. ges. Physiol., 145, 277.

WARBURG, O. [1913]. *Antwort auf vorstehende Bemerkung Thunbergs.*
Zeitsch. physiol. Chem., 87, 83.

WARBURG, O., AND MEYERHOF, O. [1913]. *Ueber Oxydation von Lecithin in Gegenwart von Eisensalz.*
Zeitsch. physiol. Chem., 85, 412.

WARBURG, O., AND USUI [1912]. *Ueber die Bindung von Thymol an roten Blutzellen.*
Zeitsch. physiol. Chem., 81, 175.

WESSON, L. G. [1924]. *The Isolation of Arachidonic Acid from Brain Tissue.*
J. Biol. Chem., 60, 183.

WESSON, L. G. [1925]. *On a Possible Relationship of Arachidonic Acid to the Saturated Fatty Acids in Fatty Acid Metabolism.*
J. Biol. Chem., 65, 235.

WHITEHORN, J. C. [1924]. *A Method for the Determination of Lipoid Phosphorus in Blood and Plasma.*
J. Biol. Chem., 62, 133.

WILSTÄTTER, R., AND LÜDECKE, K. [1904]. *Zur Kenntniss des Lecithins.*
Ber., 37, 353.

WILSON, R. A., AND CRAMER, W. [1908]. *On Protagon, its Chemical Composition and Physical Constants, its Behaviour towards Alcohol and its Individuality.*
Q.J. Exp. Physiol., 1, 97.

WILSON, R. A., AND CRAMER, W. [1909]. *A Criticism of Some Recent Work on Protagon.*
Q.J. Exp. Physiol., 2, 91.

WINDAUS, A., AND HAUTH, A. [1906]. *Ueber Stigmasterin, ein neues Phytosterin aus Calabar-Bohnen.*
Ber., 39, 4378.

WINTERSTEIN, E., AND HIESTAND, O. [1906]. *Zur Kenntniss der pflanzlichen Phosphatide.*
Zeitsch. physiol. Chem., 47, 496.

WINTERSTEIN, E., AND HIESTAND, O. [1908]. *Beiträge zur Kenntniss der pflanzlichen Phosphatide.*
Zeitsch. physiol. Chem., 54, 288.

WINTERSTEIN, E., AND SMOLENSKI [1909]. *Beiträge zur Kenntniss der aus Cerealien darstellbaren Phosphatide.*
Zeitsch. physiol. Chem., 58, 506.

WINTERSTEIN, E., AND STEGMANN, L. [1909]. *Ueber einen eigenartigen phosphorhaltigen Bestandteil der Blätter von Ricinus.*
Zeitsch. physiol. Chem., 58, 527.

WINTGEN, M., AND KELLER, O. [1906]. *Ueber die Zusammensetzung von Lecithinen.*
Arch. Pharm., 244, 3.

WOOLDRIDGE, —, [1893]. *On the Chemistry of Blood.*
Croonian Lecture, London.

WÖRNER, E., AND THIERFELDER, H. [1900]. *Untersuchungen ueber die chemischen Zusammensetzung des Gehirns.*
Zeitsch. physiol. Chem., 30, 542.

WRAMPELMAYER, E. [1893]. *Ueber den Lecithingehalt der Butter.*
Landw. Versuchstat., 42, 437.

YOSHIMOTO, S. [1910]. *Ueber den Einfluss des Lecithins auf den Stoffwechsel.*
Zeitsch. physiol. Chem., 64, 464.

ZALESKI, W. [1902]. *Beiträge zur Verwandlung des Eiweissphosphors in den Pflanzen.*
Chem. Centr., ii, 1002.

ZELLNER, J. [1911]. *Zur Chemie des Fliegenpilzes* (*Amanita Muscaria* L.).
Monats. Chem., 32, 133.

ZLATAROV, A. [1916]. *Phytochemische Studien.* I. *Mitteilung.*
Biochem. Zeitsch., 75, 200.

ZLATAROV, A. [1925]. *Phytochemischen Studien.* II. *Mitteilung.*
Biochem. Zeitsch., 161, 379.

ZUELZER, G. [1899]. *Ueber Darstellung von Lecithin und anderen Myelinsubstanzen aus Gehirn- und Eigelbextracten.*
Zeitsch. physiol. Chem., 27, 255.

ZUNZ, E., ET LE BARRE, J. [1921]. *Recherches sur l'action des phosphatides dans la coagulation du sang.*
Arch. intern. de physiol., 18, 116.

INDEX.

PRINTED IN GREAT BRITAIN BY THE UNIVERSITY PRESS, ABERDEEN